DAMOS - Mussel Watch
Western Long Island Sound Disposal Site
Monitoring Project
June 1,1984 - June 1, 1985

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Executive Summary

Biological monitoring of Western Long Island Sound Disposal Site (WLIS) was conducted from June 1984 to June 1985 using mussels (Mytilus edulis) suspended from underwater platforms. The mussel monitoring platforms were deployed at four stations: WLISc and 500MW, on and near the disposal site, WLISrN, the reference station, and RIr or LATr, the master reference station at Eastern Long Island Sound. Monitoring criteria included the tissue concentrations of nine trace metals and three PCB Aroclors (1242, 1254 and 1260), the tissue wet and dry weight ratios, and the mortalities and histopathology of the mussel populations. In addition, extrinsic factors such as water temperatures, quantities of dredged material disposed and period of disposal activities were also recorded. The objectives of the mussel watch project were to determine (1) whether or not increases in tissue concentrations of trace metals and polychlorinated biphenyls were associated with on-going open-water disposal of dredged materials and (2) whether or not such increases were correlated with changes in mortalities, in tissue wet/dry weight ratios, in gonadal development, as well as in histology.

Trace Metal Data. Trace metal results indicated similar significant spatial and temporal variations as reported in our previous 1983 and 1984 studies at the Central Long Island Sound (CLIS) and WLIS disposal sites (Feng 1984, 1985). Spatial variations in Cd, Cu and Zn tissue concentrations were noted among the mussel populations held at the four stations; levels of these three metals were significantly lower in the population at the master reference station, RIr, than in the other three populations. The reference station, WLISrN, displayed the same variations in tissue concentrations of Cu, Cd, and Zn, as the two disposal site stations, WLISc and 500MW, indicating that the concentrations were not associated with the disposal of dredged materials at the WLIS disposal site.

Temporal or before-during disposal differences in the tissue concentrations of Co, Cu, and Fe were observed in the three mussel populations deployed in western Long Island Sound. In all cases the three tissue trace metal concentrations before disposal were significantly lower than those during disposal. Although no post-disposal data were available, based on our previous experience, we could predict that the elevated levels of the trace metals encountered in mussels during the disposal period were transient and of short duration.

PCB data. Similar conclusions as presented for the trace metals could also be drawn from the PCB results. There was a discernible increase of the tissue PCB concentrations in all four of the mussel populations. Hence, no spatial difference could be attributed to the disposal activity at WLIS. Heightened levels of Aroclor 1242 and total PCBs associated with the disposal operation were observed at WLISc and WLISrN. Because

the resources provided for the present investigation did not allow for examining all sources of PCB in the environment, i.e., dry fallout, riverine contribution, PCB associated with seston, etc. (dredged material was not the only source), even in cases where correlations were established, e.g. before-during disposal difference in PCBs, causation could not be assumed.

The general conclusion that disposal of dredged material played a minor role in elevating the tissue trace metal and PCB concentrations, was further augmented by the results obtained from employing the procedures of stepwise multiple regression analysis. It was shown that intrinsic variables, i.e., wet/dry ratios and shell length, not disposal volume, could account for a major proportion of variance observed in the tissue trace metals. The disposal volume as an independent variable entered only ca. 28% of the cases, and it ranked third or fourth when it entered the regression model. For the tissue PCB concentrations obtained at WLISc and 500MW, 50-80% of the variance could be explained by the intrinsic variables. The only exception was the Aroclor 1242 concentration at WLISc where the volume of dredged material disposed accounted for 74% of its variance.

Mortalities. The patterns of cumulative mortalities of the four mussel monitoring populations were similar to those of the trace metals levels. Generally there was no spatial difference that could be attributed to the disposal operation between the reference population, WLISrN and the two populations closest to the disposal site, WLISc and 500MW. The sharp increase of cumulative mortalities from January to March 1985 at WLISc appeared to be associated with the accelerated disposal activity at the site. Because this was the only population to exhibit such a trend, it is surmised that the effect of disposal on mortality, if any, was limited to the immediate disposal area.

Histopathology. Among the seven criteria examined, there was evidence to suggest that retardation of gonadal development, Leydig tissue staining characteristics, and the absence of crystalline style and changes in kidney tubules could be associated with the placement of mussels at WLISc and 500MW and by inference with disposal activities. However, these results should be considered only as a presumptive and the interpretation tempered with caution for the following reasons:

1. Field experimental results are by nature correlational, therefore, no causation can be assumed; and

2. The histopathology results presented herein were derived from mussels which survived mortalities of undetermined causes and hence, represented the "fittest" particularly at the three transplanted stations in the western Sound (WLISc, 500MW and WLISrN), where the average cumulative mortality was more than 70%.

The results could be biased in favor of lesser spatial association with the observed abnormalities. If all the dead and dying mussels had been recovered by more frequent sampling and their tissues examined, more definitive conclusions might be reached.

Introduction

Western Long Island Sound Disposal Site

The Western Long Island Sound disposal site (WLIS) located 8.33 kilometers southeast of Stamford Harbor is near a historic site (Eatons Neck) and one of the deepest disposal sites (40 meters) in Long Island Sound (Fig. 1). It was opened in March 1982 and began to receive dredged materials in April 1982; a total of 43,063 cubic meters (56,325 cubic yards) of dredged materials were deposited that year. During its second (1983) and third (1984) years of operation, 114,405 and 126,923 cubic meters (149,635 and 166,008 cubic yards) of dredged materials were disposed respectively. In the fourth year (1985), 298,518 cubic meters (390,445 cubic yards) were disposed (Table 1, Fig. 2). During the time of this study, June 1984 to June 1985, a cumulative volume of 304,622 cubic meters (398,445 cubic yards) of dredged material were disposed. The largest volumes of dredged material were deposited between January and June of 1985, with April claiming the highest monthly volume of 119,518 cubic meters (156,330 cubic yards).

Most of the dredged materials came from various Connecticut and New York marinas as well as boat yards operating in Western Long Island Sound, and differed presumably in their chemical contents from those disposed at the Central Long Island Sound disposal site, which were of industrial harbor origin.

Eastern Long Island Sound Reference Station

Ram Island reference station (RIr) (Fig. 3) in Fishers Island Sound is located approximately 260 meters south of Ram Island and served as the master monitoring reference as well as the source of mussels for the other three mussel monitoring platforms. The depth of this location varies from 10 to 12 meters. The sea bottom is generally paved with mixed gravel, shells, and mud; its boulder-dotted surrounding is interspersed with outcrops of relic clay banks.

The Latimers Light reference station (LATr) has similar sea bottom features as the Ram Island station and was the source of mussels for restocking the three experimental platforms in March 1985 when Ram Island mussels were not available due to natural mortality.

Project Objectives

The principal objective of this study was to monitor possible deleterious effects on the environment during on-going open water disposal of dredged materials in Long Island Sound;

the DAMOS Mussel Watch Project was concerned with the following questions:

1. Is there any evidence suggesting that increases in trace metals and polychlorinated biphenyls (PCBs) in Mytilus edulis were associated with on-going open water disposal of dredged materials?

2. Is there any physiological change, e.g., tissue wet/dry weight ratios, gonadal development in M. edulis that could be attributable to the increase in tissue trace metal and PCBs concentrations?

3. Is there any discernible histopathological change that could be correlated with the increase in tissue trace metal and PCBs concentrations?

Experimental

Field Operations

Monitoring at the WLIS disposal site was initiated in June 1984 with the deployment of three experimental platforms (WLISrN, WLISc and 500MW) and a master reference platform (RIr) (Fig. 4). Our original plan of using Latimers Light mussels as a source population stock had to be modified due to the lack of mussels of the required size class (>2.5 cm) sufficient to stock the four platforms. An older mussel population from Ram Island Reef, which generally exhibited similar trace metal concentrations as those found in the Latimers Light population, was found in sufficient numbers for our purpose. More than 6,000 mussels were collected from this location, sorted, counted, bagged and held briefly at the Marine Research Laboratory dock until they were deployed at the three experimental stations. The rationale of using one population of mussels as sentinel organisms for all disposal site stations has been discussed in our previous reports (Feng, 1984, 1985).

The deployment of the three mussel monitoring platforms at western Long Island Sound was accomplished on June 27, 1984 at (1) the center of the disposal mound (WLISc), (2) 500 meters west of the mound center (500MW) and (3) a reference station located 2.22 kilometers south of the mound (WLISrN). On the following day, June 28, 1984, a platform was also deployed at Ram Island Reef (RIr) serving as a master reference station for the other three stations. Each platform was stocked with 1350 mussels in 27 mesh bags (50 mussels per bag). Details of the field operation are summarized in Table 2.

Our standard field sampling procedure requires that ten replicate baseline samples be collected for trace metal, PCBs and wet/dry weight ratio determinations when the stations were first established. Whenever restocking of the platforms was deemed necessary due to predation, mortality and irretrievable losses of the platform, replicate baseline samples were always obtained. During each monthly sampling period, weather permitting, triplicate samples of eight mussels each were collected.

Laboratory Procedures

In the laboratory the mussels were cleaned, measured, examined for infection by the pea crab, Pinnotheres maculatus, then shucked and homogenized. An aliquot of the homogenized sample was weighed (wet weight) and lyophilized using a Virtis Model 10-010 freeze drier. After being dried overnight in the apparatus, the freeze dried tissue was weighed again, and designated as the "dry weight" used in calculating the wet/dry ratio.

In addition, ten mussels each from RIr, WLISrN, WLISc and 500MW were collected monthly and fixed with one valve cracked in neutral buffered formalin for histological studies.

Trace Metal Analyses. The protocol for trace metal analyses used in this study was the same as that previously reported (Feng, 1984).

Analyses of Polychlorinated Biphenyls. Aroclors 1242, 1254 and 1260 in Mytilus edulis tissues were extracted, concentrated, cleaned and gas chromatographed according to the procedures of Arimoto and Feng (1983a). In the past, quantification of each Aroclor was accomplished manually. During the current study, quantifications of Aroclors were achieved by employing an Apple II+ microcomputer equipped with two disk drives, a ADALAB data acquisition/control card, 128K RAM card and CHROMATOCHART software (Interactive Microware, Inc., State College, PA). After the injection of the standards, the software computes retention time and actual concentrations for each peak of Aroclors 1242, 1254 and 1260 as external standards and the results are stored in the memory. The concentration of PCBs of the injected unknown samples is computed using the stored results of the external standards. A comparison of the results obtained from the manual method with that of the present procedure has shown a deviation of no more than 5%.

Gas Chromatograph/Mass Spectrophotometer Identification of Phthalate Esters. An anomalous peak present in the PCB chromatograms was identified by injecting aliquots of the sample into a HP 5890 gas chromatograph equipped with a HP 5870 MSD (Mass Selective Detector). The detected ion peak was matched

first with the 16 Phthalate ester standards. The identified sample Phthalate ester was further confirmed by matching with its known standard mass spectrum. Because the extraction procedure was designed for analyzing PCBs, the presence of Phthalate esters in the mussel extracts could only be considered as a qualitative study. Any quantitative determination of this trace organic compound would require the use of a specific extraction procedure.

Histopathological Studies. To aid fast penetration of the neutral-buffered formalin into the soft tissues of the mussels, one valve of each animal was cracked with a sharp blow using the handle of a knife, and the shell liquor drained. The mussel was immersed in the fixative so that air was not trapped inside the mantle cavity. To standardize the section, cross sections of the mussels were cut just anterior to the foot. The sections were further processed and stained with hematoxylin and eosin using the standard histological procedure by the Histology Laboratory of the Department of Pathobiology, University of Connecticut, Storrs, Connecticut.

Finished histological preparations were examined with an Olympus VANOX microscope at magnifications of 4X, 10X and 40X. Each specimen was critically scrutinized for stages of gonadal development, staining characteristics of the Leydig tissue, tissue integrity of the gill, kidney tubules, and intestinal epithelium, as well as the degree of leucocytic infiltrations. In addition, the prevalence of parasitic infections by trematodes, pea crabs, and sporozoans were also recorded.

Statistical Analyses of the Data. Prior to conducting any statistical procedure, the data set of trace metal and PCB concentrations was tested for normality using the procedure of Shapiro and Wilk (1965). If necessary, data sets were normalized by transformations (log [x], ln [x] or ![x]). Statistical analyses were performed using an IBM 3081 computer and the software for analysis of variance (ANOVA) outlined in SAS User's Guide: Statistics (SAS Inst. Inc., 1982). For the one-way ANOVA, the data were classified by station, while for the two-way ANOVA, the data were categorized by station (spatial) and sampling period (temporal), i.e. before and during disposal. In the present study, samples were collected before and during the disposal period; post disposal samples were not collected because sampling was not continued beyond June 1985. If the null hypothesis was rejected, Tukey's multiple range test (Sokal and Rohlf, 1969) was applied to discern which set(s) was different.

The frequency of the occurrence of a given parameter, e.g., gonadal development obtained from histopathological studies, was tested using the G-statistics (Sokal and Rohlf, 1969). This procedure tests the null hypothesis that the stages of gonad development or any other parameter, are independent of stations

where the mussels have been maintained. The ratios of immature and mature individuals derived from histological examinations of the four populations were further analyzed by a replicated goodness of fit test (Sokal and Rohlf, 1969) in which the total G is partitioned to yield additional information.

Results

Trace Metal Concentrations. The mean tissue concentrations of nine trace metals found in the mussel populations maintained at Ram Island reference station (RIr), Western Long Island Sound reference station (WLISrN), Western Long Island Sound disposal site center (WLISc) and 500 meters west of the disposal site (500MW) from June 1984 to June 1985 are presented with the results of two-way ANOVA and Tukey's test in Table 3. In addition, tissue trace metal data organized on a temporal basis and expressed in terms of both lg per g of wet and freeze-dried weight by station are included in the Appendix (Table 1a,b to 4a,b).

Trace metal concentrations exhibiting statistically significant differences were revealed by the two-way ANOVA ($p < 0.05$) (Table 3). The analyses indicate that the concentration of Cd, Cu and Zn show highly significant between-station differences. However, as revealed by the Tukey's Test, such differences occur only between the mussel populations maintained at RIr and the other three stations which manifested a general uniformity in the three trace metal concentrations (Table 3A). Therefore, the observed significant between-station differences were attributable solely to the RIr population which exhibited the lowest concentration of most trace metals examined (Figs. 5, 6 and 7). Because the original mussel populations deployed at the WLISc, 500MW, and WLISrN were supplemented with LATr mussels in March 1985 and sampled concurrently with the remaining original mussels, trace metal data for the newly imported mussels obtained during April, May and June 1985 were grouped separately and subjected to one-way ANOVA. The results shown in Table 4 are remarkably similar to those presented in Table 3; the same three trace metals, Cd, Cu and Zn, showed significant between-station differences. The results, therefore, indicate that the disposal of dredged materials did not induce a significant localized increase in the trace metal concentrations at any of the experimental stations.

Temporal differences (before-during disposal differences) in tissue cobalt, copper and iron concentrations were observed in mussel populations deployed at WLISc, 500MW, and WLISrN (Table 3B, Fig. 6). In all cases before disposal, the three tissue trace metal concentrations were significantly lower than the during disposal trace metal concentrations. Unfortunately, the project was terminated in June 1985 before disposal was

completed. Therefore, no post-disposal samples were available. However, based on our previous experience, we could predict that the elevated levels of trace metals observed during the disposal period were generally of short duration. The elevated level of copper during disposal at WLISrN was the only inconsistency encountered in this analysis. Such an occurrence could be interpreted as being coincidental with the disposal period or attributable to other unknown environmental factors at the site; further analyses by stepwise multiple regression favor the latter interpretation.

Stepwise multiple regression analyses (Table 5) show that the volume of dredged materials disposed was correlated with the concentrations of chromium and nickel at WLISc, of copper, iron and nickel at 500MW. In contrast, for the reference populations maintained at WLISrN and RIr, dredged volume as an independent variable was not entered into the regression models. The results are consistent with our previous studies that show the intrinsic variables, W/D and L, generally could account for the major proportion of variance observed in the tissue trace metals. There are two lines of evidence suggesting that dredged material disposal played a minor role in the uptake of trace metals by the mussels; these are (1) the dredged volume entered only ca. 28% of the cases and (2) it was the third or fourth variable entered into the model. The figure of 28% was derived from the assumption that if the elevated levels of the nine trace metals were associated with the dredged volume at WLISc and 500MW, one would expect that the dredged volume entered all 18 cases (2 stations x 9 trace metals) of the stepwise multiple regression analyses. In the present study, the dredged volume entered the regression model as an independent variable only on 5 occasions (5/18, or ca. 28%).

Polychlorinated Biphenyl (PCBs) Concentrations. The mean concentrations of the Aroclors and the total PCBs from the four mussel monitoring populations are summarized in Table 6. Temporal variations in tissue Aroclors and PCBs are presented in the Appendix (Tables 5-9). The mean concentrations of Aroclor 1242, 1254 and 1260 fall in two distinct groups: the RIr and the three populations in western Long Island Sound. The latter has nearly twice the Aroclor concentrations of the RIr population. When the data sets were subjected to two-way ANOVA, the null hypothesis that there were neither spatial (station) nor temporal (before-during disposal) differences in Aroclor concentrations among the four mussel populations, was rejected. PCBs showed significant between-station differences (Table 6, For Aroclors 1254+1260: $F=6.92$, d.f.=3,35, $P=0.0009$; For Total PCBs: $F=4.43$, d.f.=3,35, $P=0.0097$), while the Aroclor 1242 and total PCBs exhibited temporal or before-during disposal differences in mussel populations held at WLISrN and WLISc (level of significance see F values listed in Table 6B). Further analyses of the concentrations of Aroclors 1254+1260 and total PCBs using

Tukey's test revealed that no between-station differences occurred among the three mussel populations (WLISc, 500MW and WLISrN) and that the Aroclors and PCB concentrations were significantly less in the RIr population than in the other three. The concentrations of Aroclor 1242 and total PCBs were different before and during disposal in the mussel populations placed at WLISrN and WLISc; both compounds were significantly higher during disposal operations ($p < 0.046$ to 0.001). The findings of significant temporal and spatial variations in Aroclors and total PCB concentrations are similar to that of the trace metal data (Cd, Cu, Zn, Fe) discussed in the previous section.

Stepwise multiple regression analyses (Table 7) show that the volume of dredged materials was entered only into the disposal site stations (WLISc and 500MW). At WLISc, the volume of dredged materials disposed was the first variable entered into the regression model and accounted for 73.6% of the variance in Aroclor 1242. Sixty to 80% of the variance of other Aroclors and total PCBs could be explained by such intrinsic factors as W/D ratio and shell length. Similar observations were made at 500MW, i.e., 50-75% of the variance in Aroclors 1242, 1254, 1254+1260 and total PCBs were attributable to the intrinsic variables. However, the dredged volume did account for 9, 13, and 21% of the variance in total PCBs, Aroclor 1260 and Aroclors 1254+1260 respectively at this station. Again the analyses suggest that the disposal operation was not a major factor for the uptake of PCBs in the monitoring populations. This observation is consistent with changing levels of PCBs associated with dredging operations reported in San Francisco Bay (Anderlini et al., 1975), Puget Sound (Engler, 1979), Eastern Long Island Sound (Arimoto and Feng, 1983a), and Central and Western Long Island Sound (Feng, 1984, 1985).

A significant compositional change in tissue Aroclors in favor of higher chlorinated Aroclors (1254+1260) were first reported in 1984 (Feng, 1984) when the mussels were transplanted from LATr to CLIS and WLIS disposal and reference sites. Such changes have again been evident in the present study (Table 8). The percent relative concentrations of Aroclors 1242 and 1254+1260 showed significant station-differences as revealed by one-way ANOVA ($F=6.15$, d.f.=3,39, $p<0.0016$). Further analyses of the data by Tukey's test indicate that the RIr mussel population was significantly different from the other three mussel populations in their relative tissue concentration of Aroclor 1242 and Aroclors 1254+1260 (Table 8). It is apparent that the 45:55 Aroclor 1242/Aroclor 1254+1260 ratio for the RIr population differed markedly from 33:67 for the other three populations.

Bis (2-ethyl hexyl) Phthalate. During the analysis of tissue PCB concentrations, it was found that ca. 40% of the GC chromatograms (or 67 samples) showed an anomalous peak near the end of the run (Fig. 8). Contamination of the samples has been

ruled out by incorporating procedural blanks which showed no such anomalous peak. Gas Chromatography/Mass Spectrometry analysis of the samples was then carried out using a Hewlett-Packard 5890 GC and 5870 SMD system equipped with a 12 m cross linked methyl silicone (0.33 l) fused silica capillary column. The total ion concentration pattern showed a single peak with the retention time of 25.92 minutes, which matches with the thirteenth peak of Bis (2-ethyl hexyl) Phthalate (BEHP) standard (Fig. 9A, B). The confirmation of this trace organic compound is shown in the mass spectrum (Fig. 9C, D). Bis (2-ethyl hexyl) Phthalate is the most common plasticizer in use by industry. According to Giam (1976), the national annual production of BEHP was 200 million kilograms in the 1970's or six times the amount of the known pollutants, the PCBs. The solubility of BEHP in water is 0.04-0.40 ppm (Giam et al., 1984). Di-n butyl Phthalate (DNBP), a related Phthalate ester which has a solubility of 10-13 ppm in water (Giam et al., 1984) was found nearly 100% associated with particulates in Thames River water samples according to Dr. A. Libbey, Associate Professor of Chemistry, Department of Chemistry, University of Connecticut. BEHP, which is much less soluble in water than DNBP, is also expected to show a close affinity with particulates in environmental samples. Possession of such a property could be useful in serving as a particulate-borne or particulate-transported pollutant tracer.

Frequency of occurrences of BEHP in Mytilus edulis maintained in both eastern (ELIS) and western Long Island Sound throughout the year is presented in Table 9. The highest frequency at ELIS was during July, August and September, while at WLIS it was during October, November and December ($p < 0.05$). The reason for the discrepancy is not known and would have required further studies outside the scope of this investigation.

Mortalities. Prior to examining the prepared tissue sections for evidence of histopathologic changes, an attempt was made to obtain a first approximation of the possible adverse effects on the mussels by analyzing the cumulative mortalities. Figure 10 shows the differences in cumulative mortalities between the populations at RIr and in western Long Island Sound. The populations differed in the times required to reach 50% cumulative mortalities, i.e., 2, 2.5 and 3 months for the WLISc and 500MW, WLISrN, and RIr populations, respectively. The maximum cumulative mortalities: 50% for RIr and 70-90% for WLISrN, WLISc and 500MW were attained in September, three months after the deployment of mussels. WLISc population appears to be the only exception, and shows a steady increase of the cumulative mortalities from 65 to 90% during the period of January through March when disposal of dredged materials was taking place at this site. This observation suggests that the apparent disposal-associated mortality is limited to the immediate environment of the disposal site. The RXC contingency table of dead and live mussels observed in the four populations throughout the year is

used to test the hypothesis of independence of mortalities from the stations (Table 10); the G-test statistics obtained: G=234.2, v^2 0.005(4) = 14.860, p << 0.001 reject the hypothesis. Therefore, the mortalities were associated with the stations where the mussel populations were deployed. At the reference station RIr, the 45% mortality was significantly lower than that of the LATr (52%) and the three populations, WLISc, 500MW and WLISrN (71-73%). In investigating the effects of stock and location on growth and mortality in Mytilus edulis in Nova Scotia waters, Dickie et al. (1984) reported that location was the major factor in determining growth, while stock influenced mortality. Furthermore, the biomass and potential yield were determined approximately equally by location and stock. In the present study, because only one stock was used, the genetic effect was, therefore, removed. Thus, the observed differences in mortality (Table 10 and Fig. 10) and W/D ratio (potential yield) (Fig. 5) were site-specific.

Histopathological Studies. Histological sections from the reference and disposal site populations were examined by using seven parameters: (1) the stage of gonadal development, (2) staining and morphological characteristics of Leydig tissue, (3) integrity of the intestinal epithelium, and intestinal content, (4) integrity of the style sac epithelium and the presence of crystalline style, (5) changes in plycate organ, (6) degree of leucocytic infiltrations, as well as (7) prevalence of parasitism. The first two parameters are indices of the mussel's reproductive status, while parameters 3, 4, and 5 are indices of feeding and excretion status. The degree of leucocytic infiltrations, except during the post spawning resorption of remanent ova, is an indicator of inflammation which could identify overt histopathology. The last parameter is to assess any tissue damage inflicted upon the host (mussels) by parasites; this information is important in separating environmentally induced histopathological manifestations from those caused by parasitism. Whenever possible, the parameters were scored for quantitative presentation and subject to proper statistical treatment.

For scoring the degree of reproductive conditions, the gonads were categorized in five classes: castration, early development, immature stage and spent. These stages are defined as follows:

a. Castration (C): destruction or replacement of the gonadal tissue by sporocysts of Proctoeces maculatus; sex usually undeterminable.

b. Early development stage (E): only germinal tissue present; sex undifferentiated.

c. Immature stage (I): clearly recognizable germinal follicles are present; male follicles with a thick layer of spermatids around the periphery and a few spermatozoa in the center; female follicles relatively small with peripheral oocytes and occupying rather limited areas of the mantle tissue.

d. Mature stage (M): Male follicles with or without a thin layer of spermatids but filled with mature spermatozoa; female follicles packed with mature ova; both male and female follicles having displaced most of the Leydig tissue in the mantle; gametes in gonoducts.

e. Spent (S): empty or near empty follicles with extensive leucocytic infiltration and phagocytosis.

To facilitate statistical analyses of the data, the four developmental stages: E, I, M and S were pooled into two categories: the immature stage (I) and the mature stage (M). The immature stage consisted of individuals classified as in the early development and in the immature stage; the mature stage combined individuals exhibited mature ova and/or contained remnant ova and spent germinal follicles. The frequencies of the two condensed developmental stages: I and M in the four populations are presented in Table 11. The data were subjected to a replicated goodness of fit test (G-test) (Sokal and Rolf, 1969). In the analysis, the ratios of immature and mature individuals at WLISrN, WLISc and 500MW were treated as "replicate" samples which were tested against the ratio of immature and mature (8:73) mussels found at RIr.

The analyses show that G_T, G_P and G_H are all significant. The three populations of WLISC, 500MW and WLISrN have an excess of immature individuals; the proportions of immature or mature individuals appeared to have been sampled from different populations, in spite of the fact that all three experimental populations were originated from RIr. The 500MW population has a nonsignificant excess ($G=2.958$, $p>0.05$) and the WLISrN and WLISc populations deviate significantly from the expected 8:73 ratio ($G=5.968$, $p<0.025$ and $G=19.386$, $p<0.005$, respectively). Hence, G_T is highly significant. The G_P is also highly significant, because the consistent trend favors immature mussels in the three experimental populations located in the western Sound. The significant heterogeneity G_H indicates that the magnitude of favoring immature animals is not uniform in all cases. Based on analyses of the partitioned G values, the ratios of immature to mature mussels in the four populations are not homogeneous; it can also be seen that the heterogeneity of the ratios is contributed by two populations: WLISrN and WLISc, which is verified by the simultaneous test procedure (STP). These analyses suggest that the proportions of immature mussels at WLISrN (19%) and WLISc (27%) are higher than the expected proportion at RIr (10%) and are associated with the locations.

In the course of conducting histopathological studies, we noticed that the staining characteristic of the Leydig tissue, the site of glycogen storage, ranged from light to intense red. On close inspection, it was revealed that the intense red staining was due to the presence of many large amoeboid cells with eosinophilic cytoplasm in the region. These cells are known as adipogranular cells which play an important role in the glycogen metabolism and gametogenesis (Lowe et al., 1982). The results summarized in Table 12 suggest that the four populations are fairly homogenous (G_H=4.922, d.f.=3, P=ns). The trend is in favor of the lightly stained Leydig tissues indicating reduced adipogranular cell activities and in general agreement with high percentages of mussels being in the mature stage (Table 11). The only significant difference is found in WLISrN which shows the lowest proportion of lightly stained Leydig tissues (59%) as contrasted with that of the other three populations (69-77%) (Table 12, G_T=4.206, d.f.=1, $p<0.05$). Based on these analyses, it would appear that glycogen synthesis in these mussels was probably not adversely affected.

As far as feeding was concerned, no discernible or at best marginal significant differences were found in the intestinal content of the four populations (Table 13, G=2.966, d.f.=3, $P>0.05$). However, an examination of the presence or absence of the crystalline style within the style sac as indicators of feeding activities revealed that significantly fewer mussels had styles at 500MW and WLISc than those maintained at RIr and WLISrN (Table 14, 500MW: G=7.456, d.f.=1, $p<0.01$; WLISc: G=14.073, d.f.=1, $p<0.001$). Apparently, the presence of crystalline style is a more sensitive indicator of feeding activities than the presence of food in the lumen of intestine.

In the RIr and WLISrN mussels, significantly higher percentages of the plycate organ showed enlargement of the lumen as contrasted with those deployed at WLISc and 500MW (Table 15, WLISc: G=9.475, d.f.=1, $p<0.005$; 500MW: G=7.741, d.f.=1, $p<0.010$). If one accepts the assumption that the enlarged lumen of plycate organ represents the normal functioning of the organ, then the non-enlarged lumen of plycate organ suggests functional atrophy of the organ. Occasionally, Proctoeces-induced enlargement of the lumens of the plycate organ was encountered. However, there were no significant differences in the prevalence of P. maculatus infection in the four mussel populations. The apparent dysfunction of the plycate organ could be associated with disposal.

A survey of the histological slides for parasitic infections yielded the following information:

1) the prevalence of Proctoeces maculatus in the four mussel monitoring populations was not significantly different (Table 16, G=1.967, d.f.=6, p = 0.975),

2) the prevalence of Chytridiopsis mytilovum in the WLISc population was significantly higher than the other three populations (Table 17, G_H=3.837, d.f.=3, p<0.05; WLISc: G=5.217, d.f.=1, p<0.025), and

3) the prevalence of Pinnotheres maculatus differed significantly between the RIr population and the ones deployed at WLISrN, WLISc and 500MW (Table 18, G_H=11.170, d.f.=3, p<0.025).

There was an overall 12% reduction of P. maculatus infection in the transplanted populations as compared to the RIr population.

Based upon the study of 310 slides, no significant differences in leukocytic infiltration were noted in all four mussel populations (Table 19, G=8.389, d.f.=9, p=0.50).

Discussion

Trace Metal and PCB Concentrations. In the present investigation, it was found that a suite of three trace metals, Cd, Cu, and Zn, showed no discernible difference among the three mussel populations, WLISc, 500MW and WLISrN. These observations support the interpretation that any changes in the trace metal concentrations of these elements in the monitoring populations could not be attibuted to dredged material disposal. It is significant to note that similar inferences were made in the experimental populations during 1983 and 1984 disposal operations in central and western Long Island Sound, respectively (Feng, 1984, 1985). This indicates that much more pervasive factors than the episodic disposal of dredged materials are operating in Long Island Sound.

Factors contributing to the general uniformity of trace metal concentration in the mussel populations held at reference and experimental stations in both central and western Long Island Sound could be the result of physical, chemical and biological processes and/or of disposal management processes. The capping procedure implemented during the 1983 operation at CLIS could effectively reduce the release of toxic metals into the water column, thus reducing the available trace metals to the mussels and consequently mitigating the environmental impact of disposing large quantities of relatively contaminated dredged material, e.g., the Black Rock Harbor material. A second factor is the amount of contaminant input by natural process which could be orders of magnitude larger than the amount of dredged materials

disposed in the Sound. Moreover, it is assumed that releasing of trace metals and other constituents from the sediment due to bioturbation (sediment reworking by infauna) over a vast area of the seafloor in the Sound is a continuous process. The nepheloid layer which prevails at the sediment-water interface throughout much of the area of the Sound with silt-clay bottom (including the disposal sites) is presumably the result of bioturbational activities of the resident infauna. It is believed that bioturbation of shallow sea sediment is possibly the most important factor in vertical transport of contaminants to the water column, while physical factors such as storm events, circulation patterns, residence time of water masses, etc., play important roles in large scale mixing of contaminants in the Sound.

It is reasonable to assume that vertical and horizontal mixing of water masses in western Long Island Sound (the narrowest part of the estuary) are maintained most of the time except during the warm months when large areas of hypoxia exist due to temperature stratification of the water column (Rhoads, 1987; Welsh, personal communication). Bohlen (1980) reports that dredging-induced sediment resuspension is generally small in comparison to the transport resulting from natural storm events. Additionally, sediment resuspension produced by commercial fishing activities could also be a factor contributing to particulate-bound contaminant transport; studies in the Gulf of Mexico have shown that resuspension due to shrimp trawling activities could be 10-100 times greater than that generated by maintenance dredging of shipping channels in a year (Schubel et al., 1979).

In recent years, lobster and scup fisheries have become major commercial activities in Long Island Sound; these activities may play a role in sediment resuspension with the subsequent release and transport of contaminants including trace metals and particulate-associated PCBs. Thus, sediment resuspension generated from bioturbation, mixing due to tidal currents, storms and anthropogenic activity could serve as a driving force that renders the environment more uniform, which in turn is reflected in the homogeneous concentration of trace metals and PCBs found in the three experimental mussel populations located at WLISc, 500MW and WLISrN. In addition, the lack of distinction between WLISrN and the two stations nearest to the disposal site suggests that environmental conditions in the general western Sound are unfavorable as compared to the reference station in the eastern Sound. The results of this portion of the study support the hypothesis that the intrinsic and extrinsic factors played more of a role in changes in tissue trace metal levels than did disposal activities.

Temporal and spatial variations in PCB levels behave in the same manner as the tissue trace metal concentrations. The lack

of demonstrable differences in the tissue trace metal and PCB concentrations among the three populations located in the western Sound both on (WLISc and 500MW) and off (WLISrN) the disposal site lends further support to the argument presented above. The finding of compositional change of Aroclors in favor of Aroclors 1254+1260 in the disposal site populations reflects the high concentration of suspended matter in this region; it is known that more highly-chlorinated biphenyls (biphenyls with more chlorine radicals) such as Aroclors 1254 and 1260 are closely associated with particulates and that lesser chlorinated isomers such as Aroclor 1242 are water soluble (Duinker et al., 1982a,b). One could, therefore, predict that invertebrates which are deposit and suspension feeders would contain more highly chlorinated biphenyls. Such a prediction was verified in Mytilus edulis (Feng, 1984; the present study) and in the benthic invertebrates Macoma balthica, Arenicola marina and Crangon crangon from the Dutch Wadden Sea (Duinker et al., 1983). Thus, in order to resolve the question whether the Aroclor compositional change in the experimental mussel populations was due to environmental availability of the Aroclors or to biological processes (e.g., selective uptake or depuration of Aroclors), data on the composition of Aroclors in both water (dissolved and particulate-associated Aroclors) and sediment from both the reference and disposal site would be required.

Biological Effects. Mortality is a common phenomenon in all living organisms which can be ascribed to aging, diseases, and the effects of environmental changes. The key issue is how natural mortalities can be separated from those induced by the effect of pollutants. In the present study, the heightened cumulative mortalities found in the three mussel populations located in the western Sound are probably the result of abnormal reactions superimposed on the natural seasonal mortality (the latter exemplified by the reference population at RIr). When the cumulative mortality curves depicted in Figure 10 are scrutinized carefully, one notices that the onset of heightened mortalities at WLISc and 500MW occurred during July and August; for the populations held at WLISrN and RIr, the onset was delayed and took place during August and September. Even though the magnitude of the mortalities of the two populations was different, the initial elevated mortalities found at the stations in the western Sound could not have been associated with disposal activities, because there was little or no disposal of dredged material during the summer months at the WLIS disposal site. However, there is a noted increase in cumulative mortalities at the WLISc station from January to March of 1985. This correlates with the time of renewed disposal activity at the WLIS disposal site; because this is the only station to show a marked increase in mortality, it can be surmised that the effect of disposal on mortality, if any, is limited to the immediate disposal area. The high cumulative mortalities found at WLISc, 500MW, and WLISrN in part, are probably related to other environmental conditions,

e.g., the hypoxia of bottom waters prevalent in the region during the summer.

Gonadal development of Mytilus edulis under normal conditions is the result of interactions of environmental factors, especially temperature, salinity, light and food, as well as endogenous factors such as the influence of parasitism. In the present study, the reproductive activity may also have been affected in mussels living on and near dredged material disposal sites by the changing physical and chemical conditions of the environments.

The relatively high proportion of immature gonads observed at WLISrN (19%) and WLISc (27%) (Table 11) suggest that the reproductive development of the mussels is location-specific and reflect differences in the depth at which the mussels were held, availability of food, disposal, and other associated local environmental parameters. Bayne et al. (1978) demonstrated that when mussels were experimentally exposed to temperature and food ration stresses, they produced smaller and fewer eggs than unstressed controls. Also the ripe gametes of the stressed animals occupied a smaller proportion of the mantle tissue than that of the controls. In this study, temperature probably did not play an important role in determining the gonadal development. According to Reid et al. (1979), the bottom temperatures of WLIS and Fishers Island Sound in September 1972 were 18° - 20° C and 16° - 18° C, respectively. During the winter, the bottom temperatures were rather uniform throughout Long Island Sound and varied within a narrow limit of 4° - 6° C.

The reduced proportion of mature mussels at WLISrN and WLISc implies a concomitant reduction of areas occupied by female germinal follicles in the mantle. This view is generally supported by qualitative observations of the histological slides which show diminution of female germinal follicles. Quantitative studies conducted by Arimoto and Feng (1983b) revealed that the New Haven disposal site mussel population had significantly smaller ova ($1880 \pm 140\ \mu^2$) than the New Haven reference mussel population ($1520 \pm 140\ \mu^2$) ($p<0.01$).

The reduction of areas occupied by the gametic follicles or of ovum size could also be induced by the food ration stress and the infection caused by Proctoeces maculatus. While it is difficult to conduct food rationing experiments in the field, it is possible to determine whether the mussels were feeding and carrying out normal extracellular digestion by examining the presence of crystalline styles and intestinal content in the histological slides. There were no discernible or at best marginal significant differences among the four mussel populations as far as feeding was concerned (Table 13, $G=2.966$, $p>0.5$). Moreover, at WLISc and 500MW where the depth is greater than 30 meters, diatom tests were readily identifiable in the

intestinal contents, indicating that feeding was not inhibited, and food was not limited. However, even though feeding was taking place, this did not necessarily mean that the ingested food was assimilated. The generally poor condition and significantly lower frequency of crystalline styles in the 500MW and WLISc mussel populations appeared to support this assertion (Table 14).

Examinations of the effect of parasitism on gonadal development revealed that in light infections, the development of gametic follicles was inhibited, while in severe cases, the mussels were totally castrated. Such parasite-induced castration was observed in only 34 of the 409 slides examined, constituting approximately 8%; moreover, 35% of the observed castrations were seen in the RIr population. Also, the infection among the four populations was not significantly different (Table 16). Thus, parasitism probably exerted only a limited stress on the mussels at the three experimental stations, WLISc, 500MW, and WLISrN.

In addition to the infection caused by Proctoeces maculatus, Chytridiopsis mytilovum infection in the transplanted populations was significantly higher (65-80%) than that of the RIr population (52%) (G_H=3.837, d.f.=3, $p<0.05$). Because C. mytilovum invades ova of M. edulis, this observation provides additional support for the assertion that gonadal development in the WLISrN and WLISc populations was retarded; this was reflected in the higher proportion of immature individuals at these locations.

The prevalence of Pinnotheres maculatus infection in the transplanted populations was 15% less than that of the RIr population. Once a female crab enters a mussel host, it is generally "imprisoned" for life due to its large size, which prevents its escape. The reduction in occurrence of this infection could only be explained by the death of the female crabs in situ. This finding suggests that P. maculatus is more susceptible or sensitive to the changing environment at WLIS than the other two parasites. However, the reduction of percent infections could also be interpreted as a lack of new parasite invasions into the mussel host.

Leucocytic infiltration, a well known indicator of tissue inflammation which has been used by mammalian pathologists in identifying foci of abnormal tissues was of limited use in the present study. Unlike that in mammalian hosts, leucocytic infiltration in marine bivalve mollusks is associated with the normal resorption of unspawned gametes. It is, therefore, a part of the normal function of the molluscan leucocytes. Furthermore, they also play an important role in nutrition and defense (Feng et al., 1977). In the present study, some of the heightened leucocytic infiltration could be attributed to the presence of Proctoeces maculatus and to the post spawning resorption of

remanent gametes, but none appeared to be associated with disposal operations.

The histopathological studies indicated that the retardation of gonadal development, the absence of crystalline style and the dysfunction of plycate organ could be associated with mussels at all three populations transplanted in the western Sound. However, these results should be considered only as presumptive and interpreted with caution for the following reasons:

1) Field experimental results are by nature correlational, therefore, no causation can be assumed.

2) The results could also be correlated with other unknown or uninvestigated factors, and

3) The results of histopathological studies presented herein were derived from mussels which survived mortalities of undetermined causes; hence, they represented the "fittest", particularly at the three transplanted stations (WLISc, 500MW and WLISrN) where the average cumulative mortality was more than 70%. The results could be biased in favor of lesser spatial association with the observed abnormalities. If all the dead and dying mussels could have been recovered by more frequent sampling during July, August and September with subsequent examination of their tissues, more definitive conclusions might be reached.

The chances of recovering dead and dying mussels would be improved in future projects by augmenting the initial deployment with a monthly introduction of mussels at each station, followed by sampling these introduced mussels at monthly intervals concurrent with the sampling schedule of the mussels deployed initially. This approach would achieve two objectives: the monthly deployment should reveal more clearly the relationship between uptake rates of trace metals and PCBs and associated biological effects (mortalities, histopathology, W/D ratios, etc.) and allow recovery of more morbid mussels, while the initial deployment should represent cumulative effects. Moreover, the indications suggested in this study should be followed by vigorously controlled laboratory experiments in an attempt to determine causations of the observed abnormalities.

Conclusions

This investigation suggested that the disposal of dredged material has only a limited influence on the trace metal and PCB concentrations of mussel populations deployed on or near the disposal site in western Long Island Sound. Similar tissue concentrations of Cd, Cu, and Zn were found in all three

transplanted populations in the western Sound (both on and off the disposal site), suggesting that disposal activities had no effect on tissue concentrations of these elements. Significant temporal differences were found in tissue Co, Cu, and Fe before and during disposal; unfortunately, no post-disposal samples were available. However, similar results were found during earlier transplanted mussel investigations for disposal site monitoring at central and western Long Island Sound; very limited and transient changes could be associated with disposal activities (i.e., metal levels elevated during disposal quickly returned to background levels in post-disposal samples). Therefore, one could reasonably predict that the elevated levels of Co, Cu, and Fe were of short duration and would return to background following cessation of disposal activities.

Variations in concentrations of tissue PCBs (both Aroclors and total PCBs) exhibited a pattern similar to the trace metal concentrations: no difference was found among the three populations in the western Sound, while a significant difference existed between the populations in the western Sound compared to the eastern Sound. This again supports the conclusion that the disposal operation was not a major factor for the uptake of PCBs in the experimental populations. Significant temporal differences in PCB uptake were also demonstrated, but because of the lack of post-disposal samples, it could not shown that this was a long-term change; however based on prior experience, one could predict that these elevated levels were of a transient nature.

Concurrent with the previous disposal site mussel investigations carried out in Long Island Sound, some of the measured variables of physiological change (tissue wet/dry weight ratios and overall length) generally could account for the major proportion of variance observed in the tissue trace metal and PCB concentration. Histopathological studies revealed that the only effects which could be associated with disposal activities were a fewer number of mussels with crystalline styles, a higher incidence of parasitic infection by Chytridiopsis mytilovum, and a higher incidence of mussels with possible functional atrophy of the plycate organ. Otherwise, there was no effect of dredged material disposal on mussel gametogenesis, glycogen synthesis, gut content (a measure of feeding), parasitic infections by Pinnotheres maculatus, or destruction of the gonadal tissue by sporocysts of Proctoeces maculatus. The general lack of distinctions among the three transplanted mussel populations has been attributed to the uniform environmental condition in the western Sound mediated by complex physical and biological processes (e.g., water temperature, bioturbation, tidal currents, storms, commercial fishing activities). These considerations, coupled with the correlational nature of field data, suggest that causative effects cannot be assumed. Therefore, the observed biological effects from the histopathological studies can only be

considered as presumptive, because organisms respond to a variety of environmental factors in the field.

The underlying objective of the DAMOS mussel watch program is to detect any potential for far-field impacts of dredged material disposal; this objective is accomplished by monitoring tissue uptake of selected trace metal and hydrocarbon compounds as an indicator of off-site transport of particulate-associated contaminants. To date, all mussel monitoring studies associated with dredged material disposal at the containment sites in Long Island Sound have shown the effects of disposal on trace metal and hydrocarbon tissue uptake are very limited spatially and of short duration (i.e., associated with the immediate disposal event and then a return to background levels). These results support the interpretation that sites in Long Island Sound are being effectively managed as containment sites, and any far-field impacts of dredged material disposal are non-existent or undetectable.

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Table 1. Monthly dredged materials (in cubic yards) deposited at the Western Long Island Sound disposal site from June 1984 to June 1985

Date	84 Jun	Jul	Aug	Sep	Oct	Nov	Dec	85 Jan	Feb	Mar	Apr	May	Jun
Monthly Volume	8,000	--	--	--	--	--	--	20,665	24,140	109,715	156,330	77,245	2,350
Cumulative vol.	8,000	8,000	8,000	8,000	8,000	8,000	8,000	28,665	52,805	162,520	318,850	396,095	398,445
% Cumulative vol.	2.0	2.0	2.0	2.0	2.0	2.0	2.0	7.2	13.2	40.8	80.0	99.4	100.0

Table 2. Mussel Watch Program: Chronology of Field Operations from June 1984 to June 1985.

Station LORAN-C Coordinates	1984 June 27-28	July 25-26	Aug 21-22	Sept 18-19	Nov 2 & 9	Dec 11 & 13	1985 Jan 3	Feb 11 & 13	Feb 15	Mar 26-27	June 26-27
RIr 26084.4 43991.8	platform deployed & baseline samples obtained	sampled	sampled	sampled	sampled	sampled	sampled	sampled		sampled	
WLISrN 26824.3 43963.1	Platform deployed	sampled	sampled	sampled	sampled	sampled	sampled*	sampled		sampled and restocked	sampled***
WLISc 26831.9 43975.2	Platform deployed	sampled	sampled	sampled	sampled	sampled	sampled*	sampled platform moved to 500MW prior to disposal		sampled and restocked	sampled
500MW 26835.0 43975.8	Platform deployed	sampled	sampled	sampled	sampled	sampled	**	sampled		sampled and restocked	sampled
LAIr 26063.3 43977.0	Continuous sampled monthly since Oct 1982 Restocked Jan 1984	sampled	sampled	sampled	sampled	sampled	sampled	sampled	collect mussels for restocking	sampled and restocked	sampled

NOTE: October 1984 samples were not obtained; vessels not available due to scheduling conflicts.
* Sampled on Dec. 28, 84 and considered to be the Jan. 85 samples.
** No samples obtained because of diving equipment malfunction.
*** LORAN-C malfunction - no samples obtained at this date; sampled on July 11, 85 and considered to be the June sample.

Table 3. Summary of mean wet/dry weight ratios (W/D), shell length (l) and tissue trace metal concentrations (ppm ± 1 S.D.) in *Mytilus edulis* deployed at Ram Island Reef (RIr), Western Long Island Sound reference (WLISrN), Mound Center (WLISc) and 500 meter west of the mound (500MW) from June 1984 to June 1985. All WLIS stations were restocked with Latimers Light mussels in March 1985 and sampled concurrently with the original RIr mussels.

	Stations			
	RIr	WLISrN	WLISc	500MW
W/D	7.48(1.54)	8.52(2.45)	8.61(2.47)	8.67(2.84)
L	7.06(0.22)	6.48(0.75)	6.57(0.75)	6.49(0.83)
Cd*	0.94(0.48)	1.47(0.74)	1.43(0.68)	1.37(0.72)
Cr	2.90(1.61	4.34(5.76)	3.48(2.32)	3.28(3.81)
Co*	0.83(0.84)	0.91(0.91)	0.87(0.94)	0.80(0.94)
Cu*	7.68(2.06)	10.96(3.32)	11.27(2.71)	11.28(2.97)
Fe*	232(81)	263(118)	311(165)	277(130)
Hg	0.198(0.053)	0.180(0.075)	0.200(0.065)	0.178(0.059)
Ni	3.31(1.33)	4.33(2.47)	3.42(1.53)	3.82(1.86)
Zn*	124(37)	154(43)	159(41)	137(35)
V	2.16(1.85)	1.62(0.89)	1.51(0.68)	1.62(0.88)
n	11	11	11	10

*Two-Way ANOVA significant using trace metal concentrations weighted with W/D ratios.

Table 3, Continued

Tukey Groupings (α = 0.05):

A. Between-Station Differences

	RIr	500MW	WLISc	WLISrN
Cd	0.94	1.37	1.44	1.47
	RIr	WLISrN	WLISc	500MW
Cu	7.68	10.96	11.27	11.28
	RIr	500MW	WLISc	WLISrN
Zn	124	137	151	154

B. Before-During Disposal Differences

Trace Metal	Station	During	Before	F	P
Co	WLISc	1.29	0.56	5.35	0.050
Cu	WLISrN	12.79	9.44	6.25	0.034
	WLISc	12.73	10.04	9.48	0.013
	500MW	13.41	9.15	25.20	0.001
Fe	WLISc	381	253	12.00	0.007
	500MW	363	191	17.72	0.003

Table 4. Summary of mean wet/dry weight ratios (W/D), shell length (L) and tissue trace metal concentrations (ppm± 1 S.D.) in *Mytilus edulis* deployed at Latimers Light (LATr) and restocked at WLISrN, WLISc and 500 MW during April, May and June 1985.

	Stations			
	LATr	WLISrN	WLISc	500MW
W/D	6.10(0.04)	5.69(0.30)	6.10(0.50)	5.90(0.37)
L	5.50(0.35)	5.35(0.20)	5.41(0.11)	5.33(0.05)
Cd*	0.48(0.04)	0.69(0.18)	0.78(0.11)	0.79(0.18)
Cr	2.89(0.14)	2.65(1.77)	2.44(0.24)	2.18(0.26)
Co	0.44(0.07)	0.40(0.12)	0.42(0.11)	0.40(0.09)
Cu*	7.68(0.86)	9.09(0.49)	10.53(0.39)	10.70(0.52)
Fe	193(50)	193(105)	232(12)	237(26)
Hg	0.134(0.010)	0.094(0.068)	0.125(0.016)	0.128(0.027)
Ni	3.45(0.77)	3.43(0.39)	3.62(0.68)	3.71(0.25)
Zn*	85(6)	102(17)	100(9)	105(26)
V	1.14(0.40)	2.04(1.34)	1.74(0.50)	2.22(0.93)
n	3	3	3	3

*One-way ANOVA significant using trace metal concentration weighted with W/D ratios.

Tukey Groupings (α = 0.05)

	LATr	WLISrN	WLISc	500MW
Cd	0.48	0.69	0.78	0.79
	LATr	WLISrN	WLISc	500MW
Cu	7.68	9.09	10.53	10.70
	LATr	WLISc	WLISrN	500MW
Zn	85	100	102	105

Table 5. Stepwise multiple regression analyses for tissue trace metal concentrations involving the variable "disposed volume." % = the amount of variance in the trace metal concentration explained by the model. Variable code: L = shell length, W/D = wet/dry tissue weight ratio, T = temperature, D = disposal volume.

		Stations			
		WLISc		500MW	
Metal	Variables		%		%
Cr	1	W/D	65.1	W/D	52.6
	2	L	73.6	L	58.1
	3	D	88.8		
Cu	1	W/D	47.7	W/D	24.8
	2	L	66.0	L	40.0
	3	T	79.2	T	77.3
	4			D	91.9
Fe	1	W/D	71.0	W/D	29.8
	2	L	84.1	L	43.8
	3	T	95.6	T	87.3
	4	D	97.4	D	95.3
Ni	1	W/D	6.5	W/D	43.7
	2	L	11.0	L	60.7
	3			T	78.3
	4			D	88.3

Disposal volume (D) as a variable was not entered in the other multiple regression models dealing with Cd, Co, Hg, Zn, and V.

Table 6. Mean wet/dry weight ratio (W/D), shell length (L), concentration of total polychlorinated biphenyls (PCBs) and Aroclors in *Mytilus edulis* deployed at RIr, WLISrN, WLISc and 500 MW from June 1984 to June 1985.

Station	n	Aroclor[1] 1242	Aroclor 1254	Mean ± 1 S.D. Aroclor 1260	Aroclor[2] 1254+1260	Total[1,2] PCBs	W/D	L
RIr	11	64(21)	46(39)	36(41)	82(36)	145(49)	7.48(1.54)	7.06(0.22)
WLISrN	11	77(37)	94(58)	63(89)	157(76)	234(110)	8.52(2.45)	6.48(0.75)
WLISc	11	78(38)	95(66)	60(42)	155(66)	233(95)	8.61(2.47)	6.57(0.75)
500MW	10	83(46)	93(62)	94(87)	187(114)	270(156)	8.67(2.84)	6.49(0.83)

[1,2] Two-way ANOVA significant; 1-Before-during disposal differences; 2-difference among stations. Two-way ANOVAs were performed on log transformed data.

Tukey Groupings (α = 0.05)

A. Between-Station Differences

	RIr	WLISc	WLISrN	500MW
Aroclor 1254+1260	75	143	144	164
Total PCBs	138	215	217	239

B. Before-During Disposal Differences

Aroclors	Station	Before	During	F	P
Aroclor 1242	WLISrN	53	95	5.33	0.0464
	WLISc	50	105	22.78	0.0010
Total PCBs	WLISc	174	282	7.14	0.0255

Table 7. Stepwise multiple regression analyses for tissue Aroclor concentrations involving the variable "dredge volume." % = the amount of variance in the Aroclor concentration explained by the model. Variable code: W/D = wet/dry weight ratio, L = shell length, T = water temperature, M = month, D = dredged volume.

Aroclor	Variable	Station WLISc	%	500MW	%
1242	1	D	73.6	L	74.8
	2	L	88.5		
1254	1	W/D	60.4	W/D	61.7
	2			T	82.5
1260	1	M	38.7	M	53.9
	2			D	67.3
	1	L	68.3	L	49.0
1254+1260	2	T	77.8	D	70.3
	3	M	87.9		
	1	L	80.1	L	55.9
Total PCBs	2			T	72.2
	3			D	81.5

Dredgedvolume as a variable was not entered in the other two mussel populations maintained at RIr and wLISrN.

Table 8. Changes in the mean relative tissue concentration of Aroclors when Ram Island Reef mussels were deployed at WLISrN, WLISc and 500MW (June 84-June 85).

Station		Aroclor Relative Concentration % 1242	1254	1260	1254+1260
RIr	$\bar{x}$	44.6	32.4	23.0	55.4
	S.D.	10.4	21.4	22.9	10.4
	n	11	11	11	11
WLISrN	$\bar{x}$	32.7	43.6	23.7	67.3
	S.D.	5.9	21.9	21.2	5.9
	n	11	11	11	11
WLISc	$\bar{x}$	33.4	39.1	27.5	66.6
	S.D.	8.8	23.4	20.7	8.8
	n	11	11	11	11
500MW	$\bar{x}$	31.3	36.6	32.1	68.7
	S.D.	6.4	24.6	21.1	6.4
	n	10	10	10	10

One-way ANOVA

Aroclor 1242: $F = 6.15$, d.f. = 3,39, $P = 0.0016$
Aroclor 1254: $F = 0.46$, d.f. = 3,39, $P = 0.7113$
Aroclor 1260: $F = 0.39$, d.f. = 3,39, $P = 0.7595$
Aroclor 1254+1260: $F = 6.15$, d.f. = 3,39, $P = 0.0016$

Tukey Groups ($\alpha = 0.05$):

Aroclor	Station 500MW	WLISrN	WLISc	RIr
1242	0.31317	0.32736	0.33378	0.44629
1254+1260	0.68683	0.67264	0.66622	0.55371

Table 9. Frequency of occurrences of Bis (2-ethyl hexyl) Phthalate in *Mytilus edulis* maintained at WLIS disposal sites and ELIS reference stations.

Station	Frequency of Occurrences					% Frequency of Occurrences				
	Nov	Feb	May	Aug	Totals	Nov	Feb	May	Aug	Totals
WLIS Disposal Sites	17	5	13	3	38	44.7	13.2	34.2	7.9	100
ELIS Reference Sites	5	5	10	9	29	17.2	17.2	34.5	31.1	100

G-test Statistics: $G=9.236$, d.f.=3, $\chi^2_{0.05(3)} = 7.85$, $P < 0.05$

Frequencies and percentages of occurrence within the box are not significantly different.

Table 10. The number of dead and alive mussels found in the five populations maintained at RIr, LATr, WLISrN, 500 MW and WLISc from June 1984 through June 1985. Summary of replicated goodness of fit tests.

Station	Dead	Alive	Σ	pi	df	Goodness of Fit Test G	P
RIr	329	404	733	0.449	1	0.000	NS
LATr	340	314	654	0.520	1	13.256	<0.001
WLISrN	641	262	903	0.710	1	251.439	<<0.001
500MW	625	237	862	0.725	1	269.830	<<0.001
WLISc	756	283	1039	0.728	1	331.533	<<0.001
Σ	2691	1500	4191 = n	Total G_T	5	866.058	<<0.001
				Pooled G_p	1	631.856	<<0.001
				Heterogeneity G_H	4	234.202	<<0.001

Table 11. Gonadal development of *Mytilus edulis* deployed at RIr, 500 MW, WLISrN and WLISc from June 1984 through March 1985. Summary of replicated goodness of fit tests. I = immature, M = mature.

	Gonadal Development					Goodness of Fit Test		
Station	I	M	Σ	pi		df	G	P
RIr	8	73	81	0.099		1	0.000	NS
500MW	10	48	58	0.172		1	2.959	NS
WLISrN	15	64	79	0.190		1	5.967	<0.025
WLISc	22	59	81	0.272		1	19.386	<<0.001
Σ	55	244	299 = n		Total G_T	4	28.312	<<0.001
					Pooled G_p	1	19.957	<<0.001
					Heterogeneity G_H	3	8.355	<0.05

Table 12. The staining characteristics of Leydig tissues of *Mytilus edulis* maintained at RIr, 500 MW, and WLISc and WLISrN from June 1984 through March 1985. Summary of replicated goodness of fit tests. L = lightly stained, M + H = moderately and heavily stained.

Staining Characteristics					Goodness of Fit Test		
Station	L	M+H	Σ	pi	df	G	P
RIr	65	27	92	0.706	1	0.000	NS
500MW	49	15	64	0.766	1	1.128	NS
WLISc	54	24	78	0.692	1	0.076	NS
WLISrN	44	30	74	0.594	1	4.206	<0.05
Σ	212	96	308 = n	Total G_T	4	5.410	NS
				Pooled G_p	1	0.486	NS
				Heterogeneity G_H	3	4.922	NS

Table 13. The presence and absence of food contents in the intestine of *Mytilus edulis* maintained at RIr, WLISrN, WLISc and 500MW.

Station	Food Content Present	Absent	Σ	pi
RIr	62	27	89	0.697
WLISrN	49	20	69	0.710
500MW	43	17	60	0.717
WLISc	43	29	72	0.597
Σ	197	93	290 = n	

G-test Statistics: G = 2.966, df = 3, $X^2 0.05(3) = 7.815$, $P>0.05$.

Table 14. The presence and absence of crystalline style within the style sac of *Mytilus edulis* maintained at RIr, WLISrN, WLISc and 500MW. Summary of replicated goodness of fit tests. WS = with crystalline style, WOS = without crystalline style.

	Style Sac					Goodness of Fit Test	
Station	WS	WOS	Σ	Pi	df	G	P
RIr	81	3	84	0.964	1	0.000	NS
WLISrN	65	6	71	0.915	1	3.585	NS
500MW	52	7	59	0.881	1	7.456	<0.01
WLISc	58	10	68	0.853	1	14.073	<0.001
Σ	256	26	282 = n	Total G_T	4	25.114	<0.001
				Pooled G_p	1	18.411	<0.001
				Heterogeneity G_H	3	6.703	>0.05, <0.10

Table 15. Frequencies of enlarged plycate organ encountered in *Mytilus edulis* deployed at RIr, WLISrN, WLISc and 500 MW from June 1984 through March 1985. Summary of replicated goodness of fit tests. E = enlarged tubules, N = not enlarged tubules.

	Plycate Organ				Goodness of Fit Test		
Station	E	N	Σ	pi	df	G	P
RIr	52	39	91	0.571	1	0.000	NS
WLISrN	42	31	73	0.575	1	0.005	NS
WLISc	32	48	80	0.400	1	9.474	<0.005
500MW	25	38	60	0.397	1	7.741	<0.010
Σ	151	156	307 = n	Total G_T	4	17.220	<0.005
				Pooled G_p	1	7.850	<0.010
				Heterogeneity G_H	3	9.370	<0.025

Table 16. Frequencies of *Proctoeces maculatus* infection in *Mytilus edulis* maintained at RIr, WLISrN, WLISc and 500MW from June 1984 through March 1985. N = 0 sporocyst, L = 1-9 sporocysts, M = 10-99 sporocysts, H>100 sporocysts per section.

Station	Proctoeces Infection				% Proctoeces Infection			
	N	L	M+H	Totals	N	L	M+H	Totals
RIr	70	16	18	104	67.3	15.4	17.3	100
WLISrN	65	19	20	104	62.5	18.3	19.2	100
WLISc	73	22	13	108	67.6	20.4	12.0	100
500MW	66	13	14	93	71.0	14.0	15.0	100

G-test Statistics: G=1.9670, d.f.=6, $\chi^2_{0.975(6)}$=1.237, P<0.975

Table 17. Frequencies of Chytridiopsis mytilovum infection in female Mytilus edulis maintained at RIr, WLISrN, 500MW and WLISc. Summary of replicated goodness of fit tests. I = infected, NI = noninfected.

	Chytridiopsis mytilovum					Goodness of Fit Test		
Station	I	NI	Σ	pi		df	G	P
RIr	16	15	31	0.516		1	0.000	NS
WLISrN	17	9	26	0.654		1	2.013	>0.05
500MW	17	9	26	0.654		1	2.013	>0.05
WLISc	12	3	15	0.800		1	5.217	<0.025
Σ	62	36	98 = n		Total G_T	4	9.243	>0.05
					Pooled G_p	1	5.405	<0.025
					Heterogeneity G_H	3	3.837	<<0.05

Table 18. Frequencies of *Pinnotheres maculatus* infection in *Mytilus edulis* maintained at RIr, WLISrN, 500MW and WLISc from June 1984 through March 1985. Summary of replicated goodness of fit tests. I = infected, NI = noninfected.

Pinnotheres maculatus						*Goodness of Fit Test*		
Station	I	NI	Σ	pi		df	G	P
RIr	156	62	218	0.716		1	0.000	NS
WLISrN	103	61	164	0.628		1	5.858	<0.025
500MW	73	51	124	0.589		1	9.132	<0.005
WLISc	63	52	115	0.548		1	14.560	<0.001
Σ	395	226	621 = n		Total G_T	4	29.550	<0.001
					Pooled G_p	1	18.380	<0.001
					Heterogeneity G_H	3	11.170	<0.025

There is no difference in the frequency of *Pinnotheres* infection among the three WLIS populations ($G = 1.815$, χ^2 0.05(2) = 5.991, $p \gg 0.05$).

Table 19. Frequencies of leukocytic infiltration in *Mytilus edulis* maintained at RIr, WLISrN, WLISc and 500MW. N, L, M and H denote respectively no, light, moderate and heavy leukocytic infiltrations in the tissue sections.

Station	Leukocytic Infiltration					% Leukocytic Infiltration				
	N	L	M	H	Total	N	L	M	H	Total
RIr	19	40	23	12	94	20	43	26	11	100
WLISrN	11	33	16	14	74	15	45	22	18	100
WLISc	19	33	20	7	79	24	42	25	9	100
500MW	7	28	16	12	63	11	44	25	20	100

G-test Statistics: $G=8.389$, d.f.=9, $x^2_{0.50(9)}=8.343$, $P=0.50$

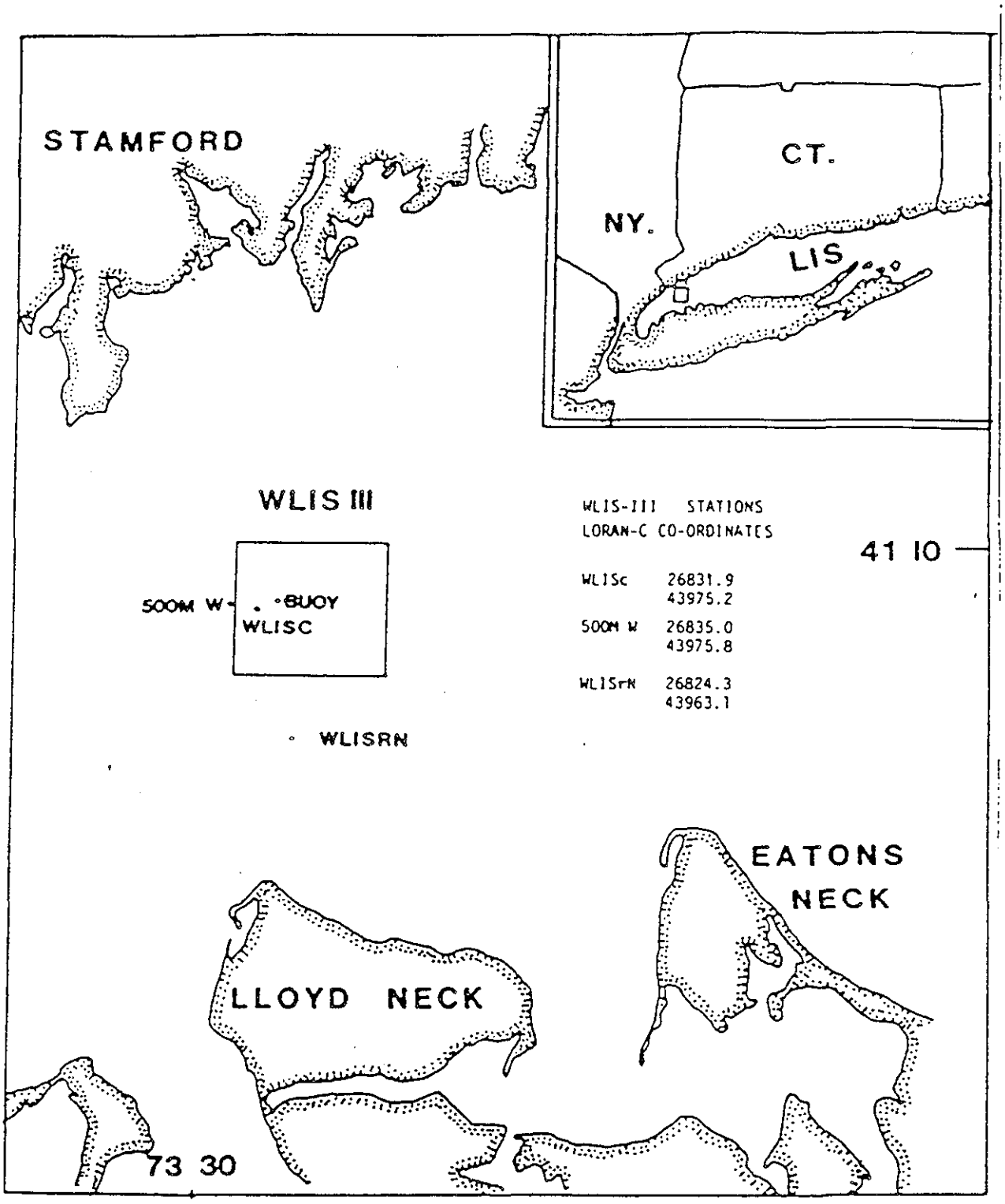


Figure 1. The Western Long Island Sound (WLIS) disposal site depicting the locations of three mussel monitoring platforms at WLISc, 500 MW and WLISrN, as well as the disposal buoy.

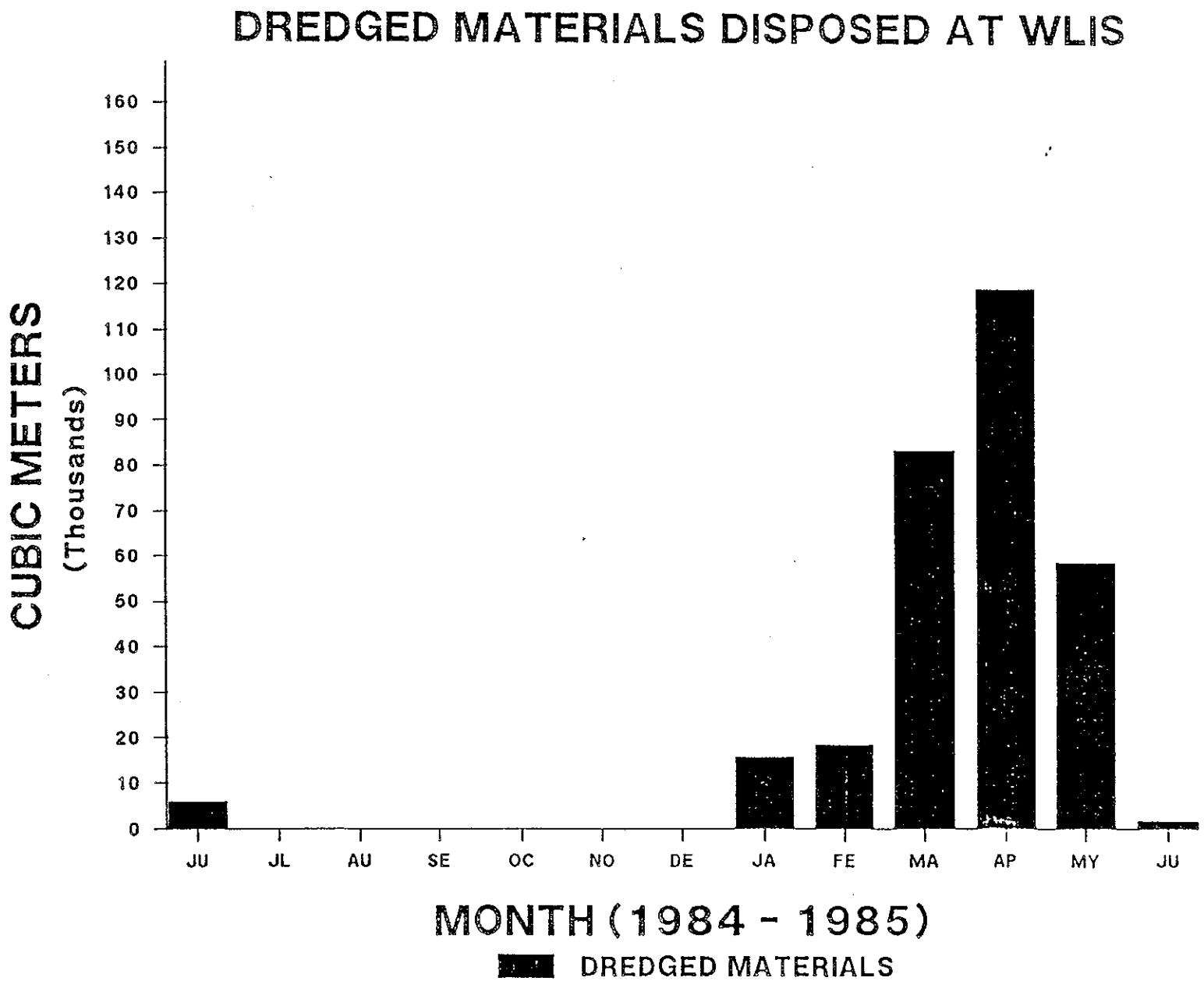


Figure 2. Dredged materials (cubic meters) disposed at the WLIS disposal site from June 1984 to June 1985.

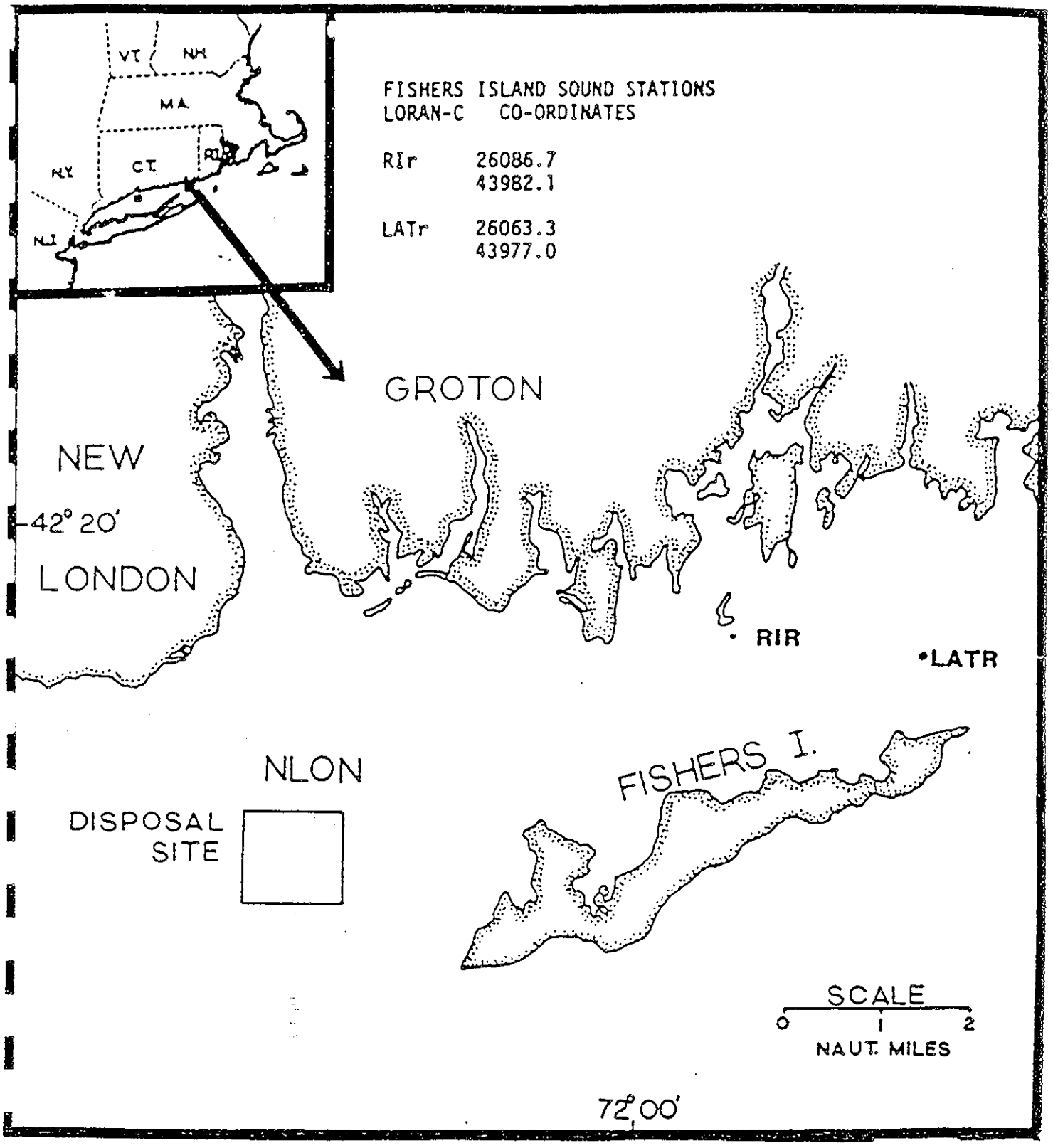


Figure 3. The Eastern Long Island Sound reference sites showing the locations of RIr and LATr.

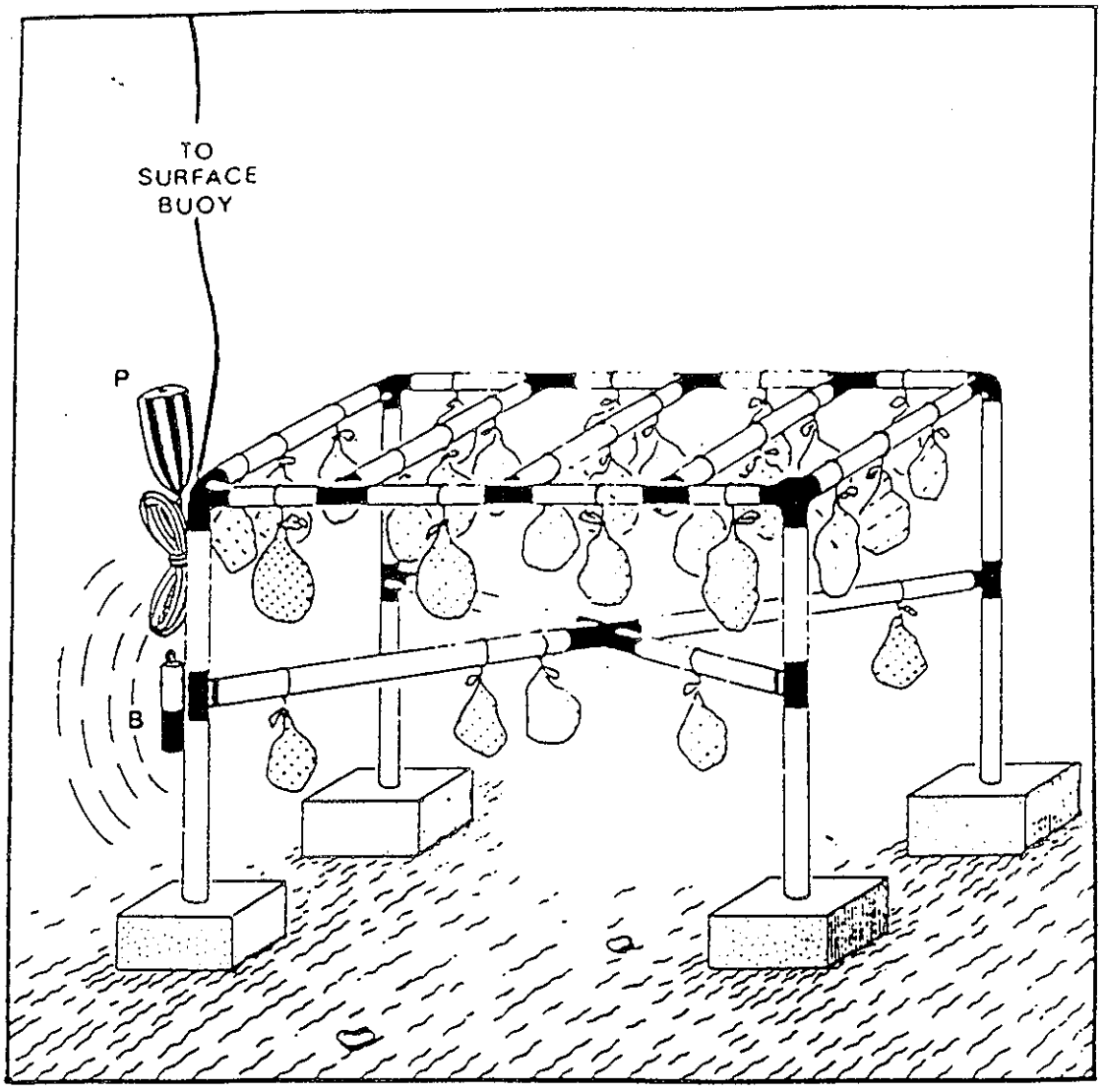


Figure 4. A monitoring platform with attached bags of mussels. Each platform was equipped with sonic beacon (B), a remotely operated acoustic release (not shown), a surface float, and a subsurface float (P). The subsurface float was released if the surface float was pulled free.

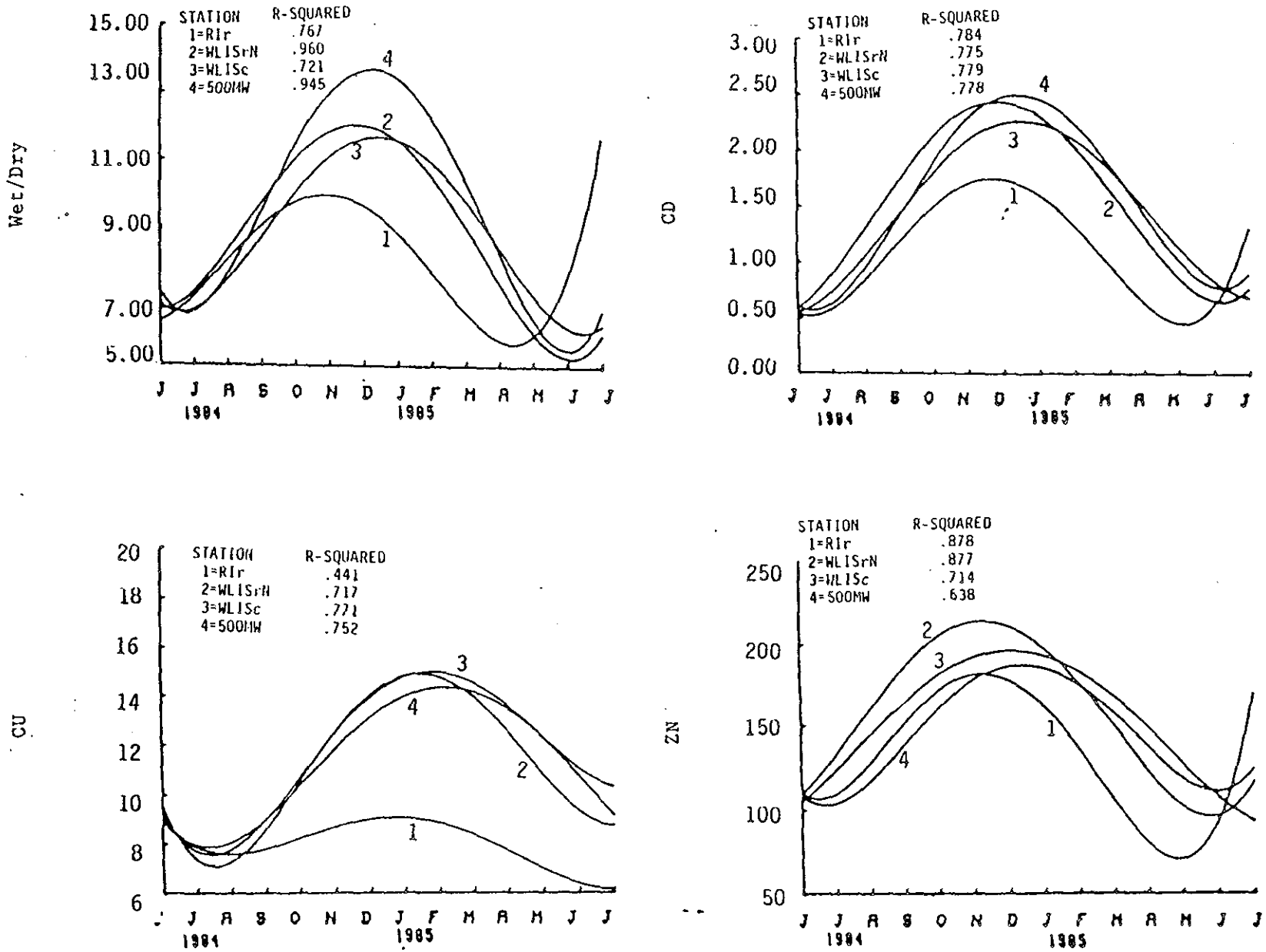


Figure 5. Temporal variation of the wet/dry tissue weight ratio and the tissue concentration of cadmium, copper, and zinc in mussel populations deployed at RIr, WLISrN, WLISc and 500MW. Significant differences in the trace metal concentrations were detected between mussels maintained at RIr and the WLIS sites (see Table 3A). Disposal operation at WLISc was conducted from January to June 1985.

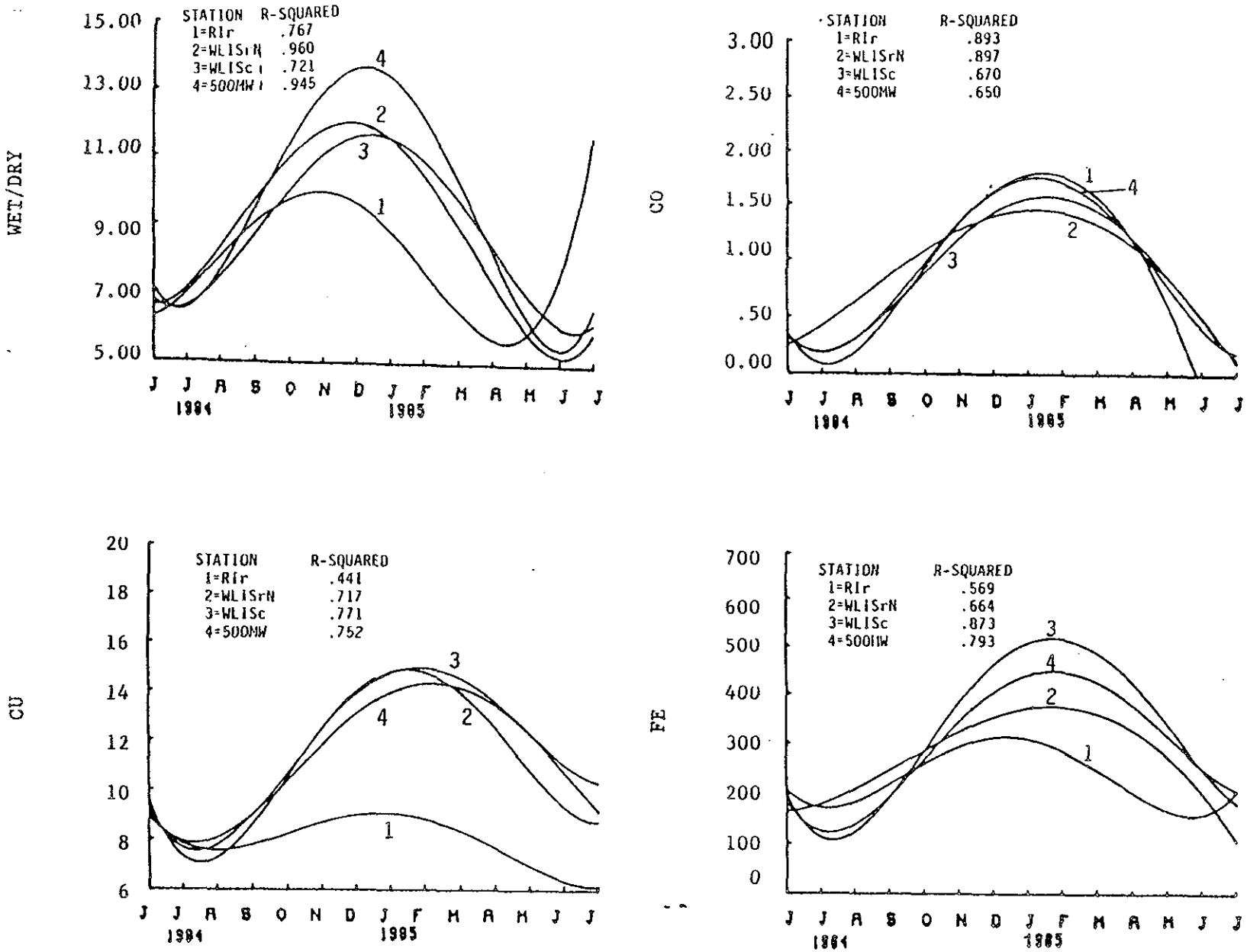


Figure 6. Temporal variation of the ration of wet/dry tissue weights and the tissue concentration of cobalt, copper and iron in mussel populations held at RIr, WLISrN, WLISc and 500MW. Significant differences in the trace metal concentration were detected before and during disposal (see Table 3B). Disposal operation at WLISc was conducted from January to June 1985.

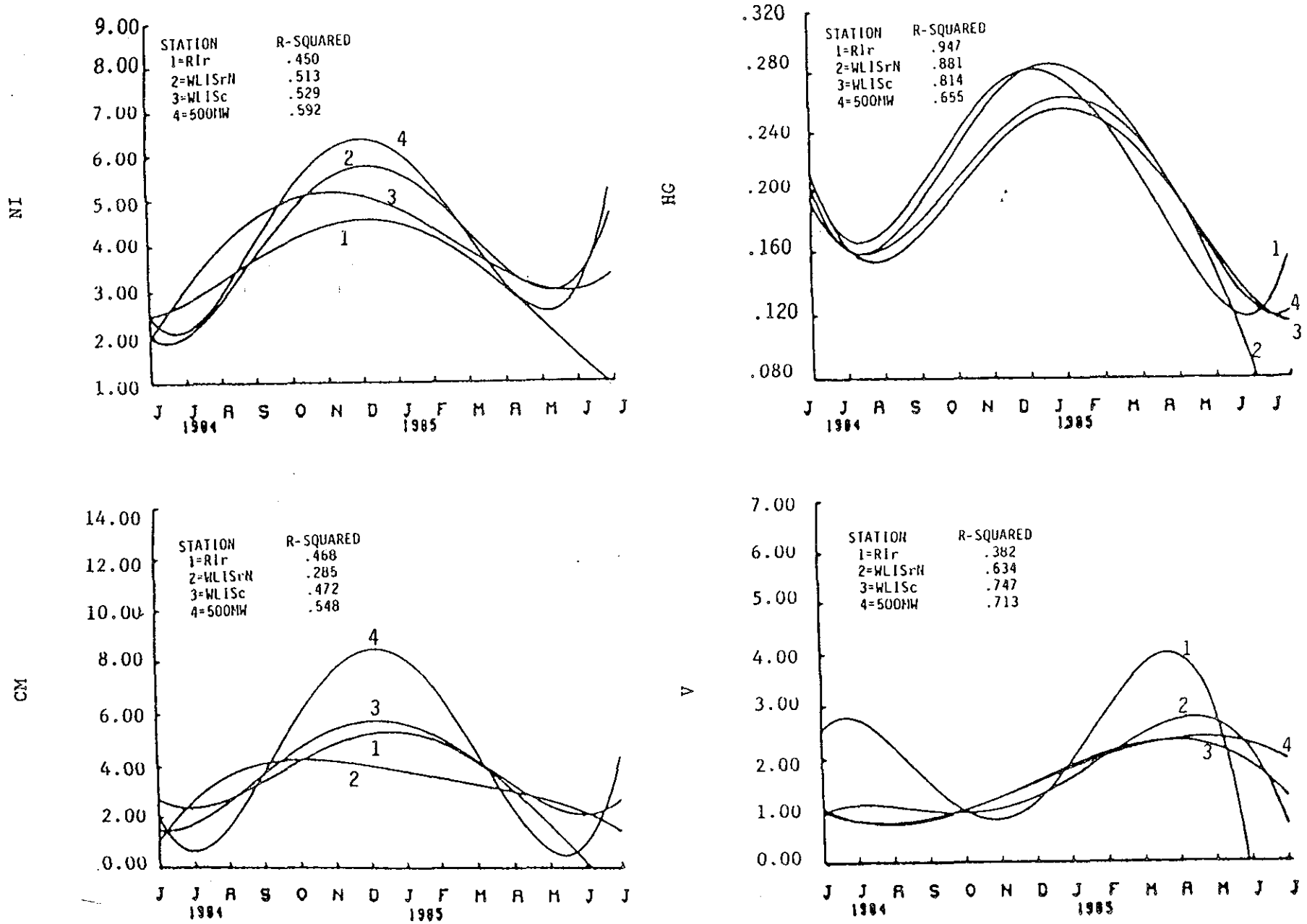


Figure 7. Temporal variation of the tissue concentration of nickel, chromium, mercury and vanadium in mussel populations maintained at RIr, WLISrN, WLISc and 500MW. However, differences among stations and before-during disposal operations were not statistically significant.

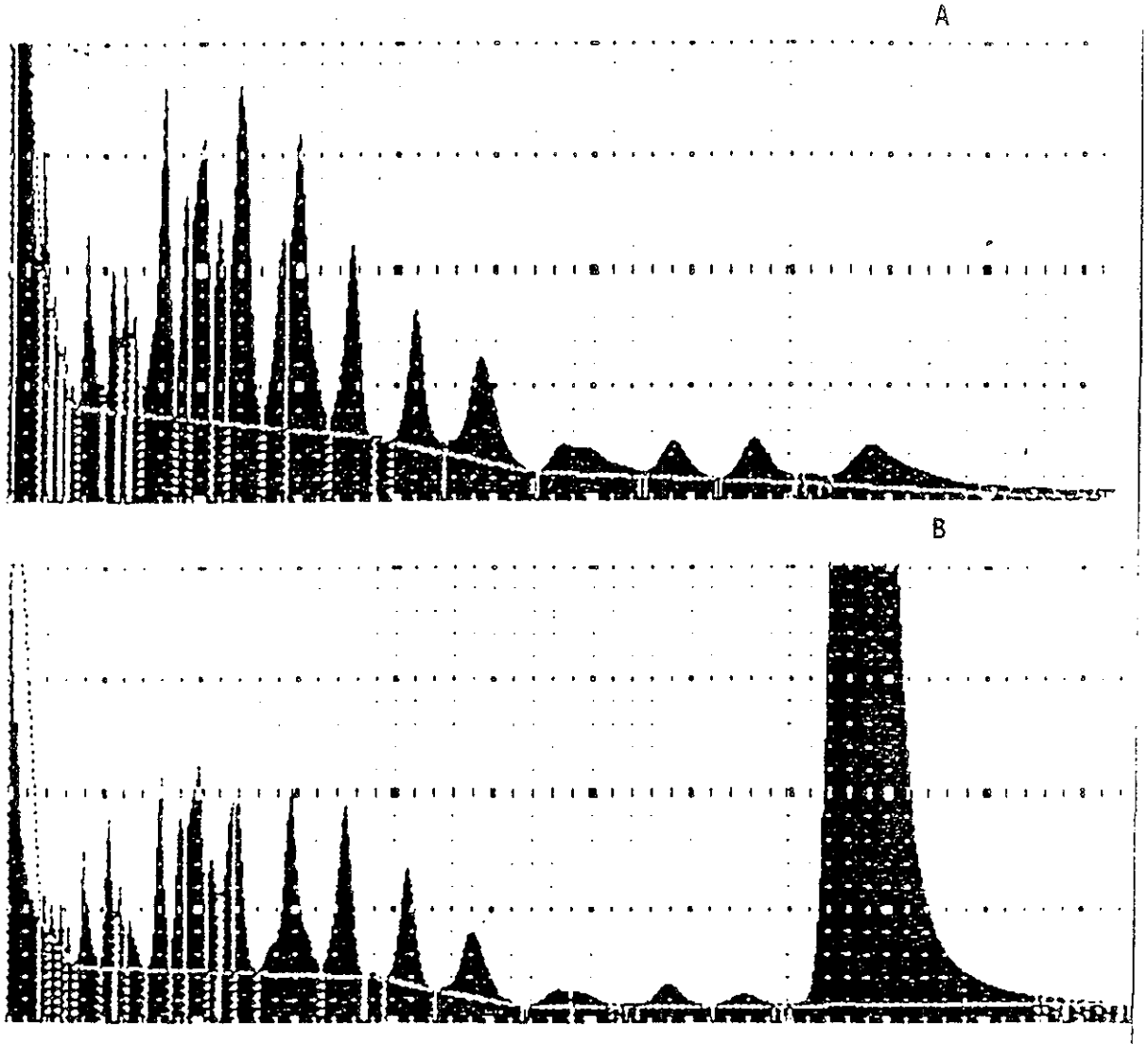
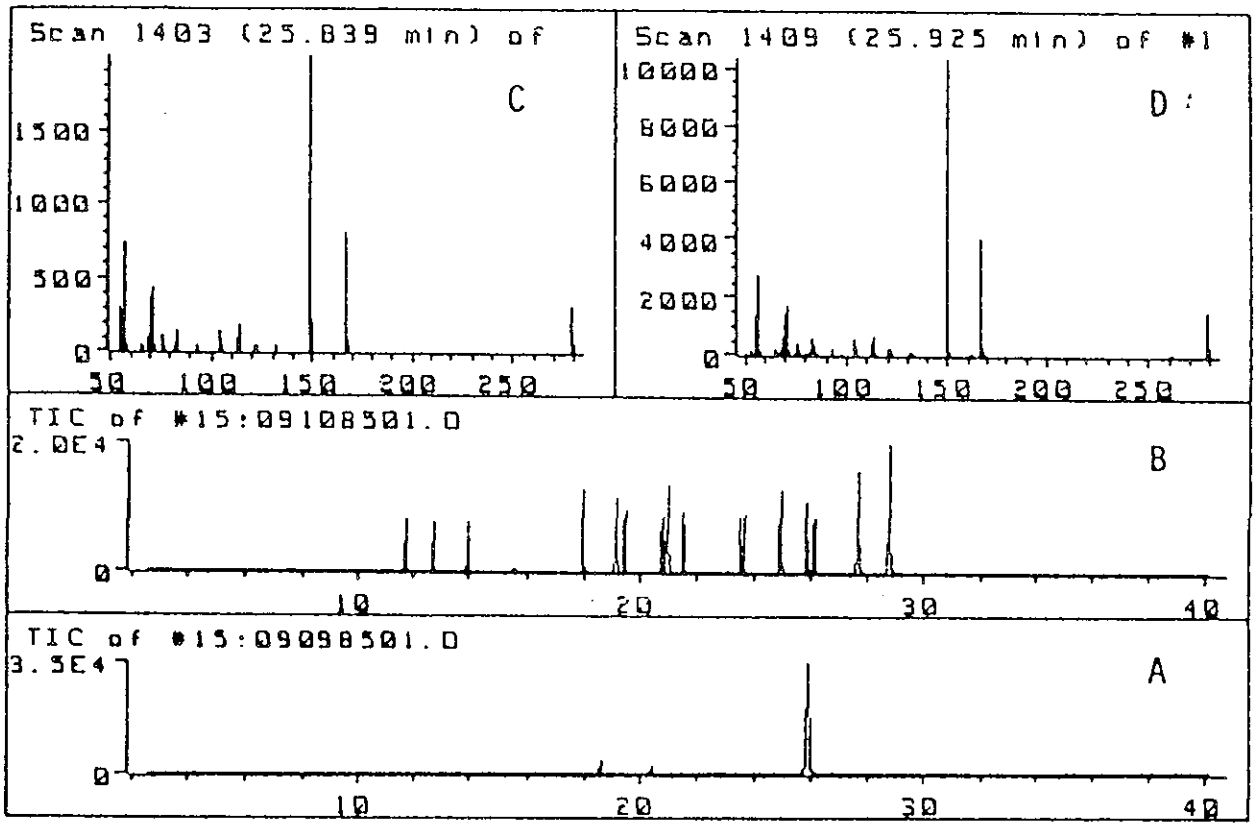


Figure 8. Two GC chromatograms of polychlorinated biphenyls from mussel tissue extracts: A. normal chromatogram, B. exhibiting a large anomalous peak.



A. Total ion concentrations of Western Long Island Sound Center Mound (WLISc) mussel sample.
B. Total ion concentrations of the 16 Phthalate ester standards.
C. Mass spectrum of the 13th peak Bis (2-ethyl hexyl) Phthalate (Standard).
D. Mass spectrum of the mussel sample from Western Long Island Sound Central Mound showing exact matching of the MS with that of the standard.

Figure 9. Gas Chromatograph/Mass Spectrometry identification and confirmation of the anomalous peak observed (Figure 5A) as Bis(2-ethyl hexyl) Phthalate.

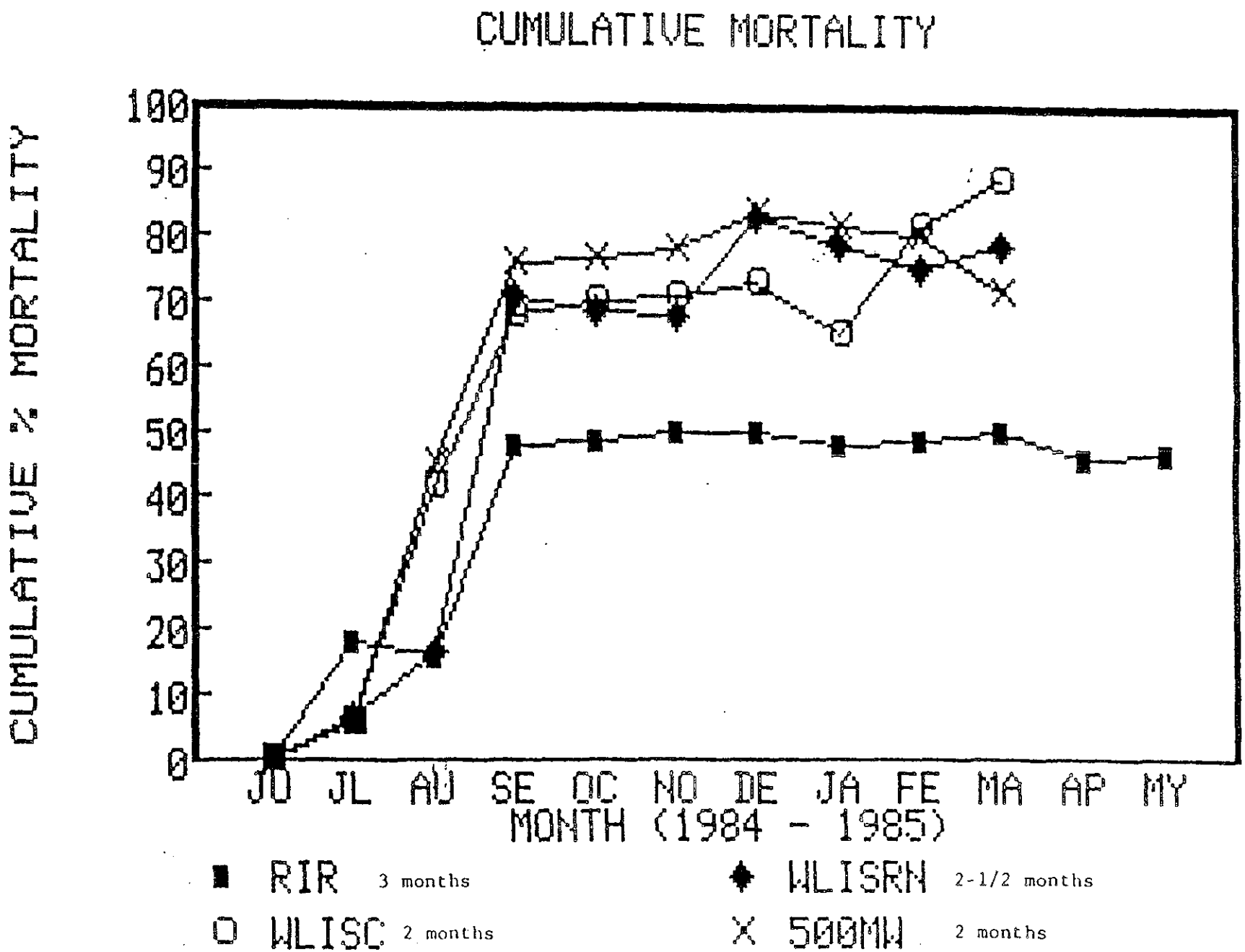


Figure 10. Cumulative mortality in mussel populations deployed at RIr, WLISrN, WLISc and 500MW.

APPENDIX

Table 1a. Summary of metal concentrations (wet weight) in mussels (*Mytilus edulis*) deployed at Ram Island reference site (RIr).

	Mean Metal Concentration ± S.D. (μg/g wet wt of tissue)								
Sampling Date	Cd	Cr	Co	Cu	Fe	Hg	Ni	Zn	V
4/26/84	.14 (.03)	.60 (.25)	.09 (.02)	1.30 (.17)	52.25 (10.71)	.027 (.004)	.53 (.26)	19.01 (6.12)	.19 (.04)
6/27/84	.07 (.01)	.29 (.09)	.03 (.02)	1.28 (.18)	26.71 (4.60)	.031 (.003)	.33 (.13)	15.18 (2.77)	.15 (.05)
7/26/84	.11 (.07)	.54 (.16)	.06 (.03)	1.29 (.28)	37.20 (4.57)	.031 (.002)	.40 (.08)	21.55 (1.63)	1.03 (.20)
8/22/84	.10 (.01)	.33 (.04)	.05 (.01)	1.18 (.16)	19.53 (.90)	.021 (.001)	.57 (.26)	13.43 (2.32)	.04 (.04)
9/19/84	.12 (.01)	.52 (.14)	.08 (.01)	.87 (.15)	27.23 (1.89)	.022 (.001)	.44 (.18)	16.09 (2.24)	.11 (.01)
11/2/84	.13 (.01)	.17 (.04)	.05 (.00)	.65 (.05)	19.62 (2.23)	.022 (.001)	.22 (.06)	16.93 (2.52)	.17 (.01)
12/13/84	.24 (.02)	.78 (.21)	.12 (.01)	1.08 (.12)	44.55 (9.41)	.035 (.001)	.70 (.12)	22.16 (3.45)	.17 (.02)
1/3/85	.14 (.01)	.40 (.26)	.23 (.02)	1.03 (.16)	25.73 (5.31)	.029 (.005)	.37 (.13)	15.10 (1.79)	.13 (.01)
2/13/85	.21 (.00)	1.20 (.02)	.45 (.02)	1.48 (.11)	53.78 (4.78)	.036 (.001)	.86 (.10)	20.07 (4.22)	.69 (.14)
3/28/85	.08 (.02)	.19 (.02)	.06 (.00)	1.28 (.32)	23.04 (1.67)	.028 (.001)	.38 (.36)	12.99 (1.65)	.72 (.11)

Table 1a, Continued

Sampling Date	Mean Metal Concentration ± S.D. (μg/g wet wt of tissue)								
	Cd	Cr	Co	Cu	Fe	Hg	Ni	Zn	V
4/26/85	.09 (.00)	.16 (.02)	.06 (.01)	.89 (.17)	27.53 (1.98)	.023 (.001)	.27 (.07)	11.89 (1.26)	.27 (.10)
05/24/85	.08 (.01)	.18 (.11)	.05 (.01)	1.13 (.32)	26.15 (5.90)	.018 (.005)	.36 (.14)	12.72 (1.58)	.15 (.04)

Table 1b. Summary of metal concentrations (dry weight) in mussels (*Mytilus edulis*) deployed at Ram Island reference site (RIr).

Sampling Date	Mean Metal Concentration ± S.D. (µg/g dry wt of tissue)								
	Cd	Cr	Co	Cu	Fe	Hg	Ni	Zn	V
4/26/84	0.68 (0.23)	4.04 (1.77)	0.58 (0.10)	8.75 (1.02)	349.56 (59.79)	.184 (.014)	3.60 (1.89)	133.76 (20.76)	1.37 (0.23)
6/27/84	0.45 (0.07)	1.90 (0.57)	0.15 (0.10)	8.32 (.74)	173.21 (24.04)	.201 (.013)	2.14 (0.78)	98.65 (16.25)	1.00 (0.28)
7/26/84	0.71 (0.40)	3.45 (1.06)	0.36 (0.16)	8.20 (1.81)	238.25 (31.20)	.195 (.009)	2.49 (0.39)	136.65 (6.39)	6.54 (1.06)
8/22/84	0.77 (0.03)	2.58 (0.40)	0.43 (0.08)	9.21 (0.92)	153.61 (4.59)	.163 (.014)	4.44 (2.00)	105.29 (14.64)	0.36 (0.34)
9/19/84	0.99 (0.18)	4.26 (1.31)	0.65 (0.05)	6.97 (0.79)	218.02 (7.56)	.175 (.025)	3.46 (1.34)	130.35 (29.13)	0.91 (0.19)
11/2/84	1.42 (0.17)	1.87 (0.50)	0.59 (0.06)	6.97 (0.30)	210.74 (13.98)	.242 (.024)	2.41 (0.77)	183.24 (35.0)	1.87 (0.11)
12/13/84	1.98 (0.27)	6.43 (2.00)	0.98 (0.09)	8.81 (0.82)	367.00 (93.41)	.283 (.012)	5.72 (1.26)	181.47 (32.17)	1.36 (0.25)
1/3/85	1.37 (0.21)	4.14 (2.80)	2.24 (0.28)	10.08 (0.44)	257.68 (22.87)	.288 (.072)	3.71 (1.52)	148.41 (8.50)	1.32 (0.25)
2/13/85	1.30 (0.05)	2.61 (0.17)	2.87 (0.14)	9.34 (0.50)	339.94 (18.61)	.227 (.003)	5.44 (0.45)	127.16 (27.86)	4.35 (0.73)
03/28/85	0.47 (0.16)	1.12 (0.17)	0.37 (0.02)	2.38 (1.77)	133.24 (14.14)	0.160 (.000)	2.19 (2.02)	74.75 (6.49)	4.12 (0.43)

Table 1b, Continued.

Sampling Date	Mean Metal Concentration ± S.D. (μg/g dry wt of tissue)								
	Cd	Cr	Co	Cu	Fe	Hg	Ni	Zn	V
04/26/85	0.58 (0.07)	1.07 (0.22)	0.43 (0.05)	5.83 (0.67)	180.68 (7.45)	.152 (.014)	1.82 (0.61)	78.24 (9.51)	1.79 (0.70)
05/24/85	0.52 (0.03)	1.35 (0.66)	0.36 (0.03)	7.25 (0.81)	163.92 (15.80)	.113 (.075)	2.26 (0.53)	83.52 (4.85)	0.95 (0.10)

Table 2a. Summary of metal concentrations (wet weight) in mussels (*Mytilus edulis*) deployed at Western Long Island Sound reference site (WLISrN).

	Mean Metal Concentration ± S.D. (μg/g wet wt of tissue)								
Sampling Date	Cd	Cr	Co	Cu	Fe	Hg	Ni	Zn	V
7/25/84	.11 (.02)	.22 (.07)	.04 (.03)	1.24 (.20)	25.49 (3.22)	.025 (.002)	.42 (.03)	21.62 (1.02)	.20 (.03)
8/25/85	.23 (.02)	.13 (.04)	.09 (.03)	1.10 (.11)	16.23 (1.10)	.022 (.004)	.30 (.04)	18.99 (1.53)	.06 (.02)
9/18/84	.15 (.01)	2.45 (3.03)	.13 (.04)	.87 (.26)	30.94 (13.14)	.019 (.004)	1.09 (.78)	17.15 (5.97)	.09 (.01)
11/9/84	.17 (.02)	.30 (.24)	.07 (.01)	.80 (.07)	28.89 (1.73)	.020 (.001)	.38 (.14)	20.21 (4.56)	.17 (.03)
12/11/84	.17 (.01)	.25 (.06)	.07 (.01)	1.14 (.26)	25.40 (6.61)	.021 (.005)	.39 (.04)	16.63 (2.14)	.07 (.01)
12/28/84	.22 (.02)	.48 (.23)	.07 (.02)	1.32 (.06)	28.49 (5.57)	.021 (.003)	.53 (.15)	17.72 (4.15)	.13 (.01)
2/11/85	.25 (.02)	.22 (.01)	.32 (.05)	1.62 (.10)	47.08 (11.98)	.029 (.006)	.33 (.02)	16.35 (3.21)	.21 (.06)
3/26/85	.16 (.00)	.21 (.06)	.09 (.01)	1.81 (.15)	35.03 (4.84)	.024 (.000)	.32 (.04)	18.45 (0.97)	.32 (.03)
4/25/85	.09 (.01)	.81 (.30)	.06 (.00)	1.55 (.20)	47.45 (2.91)	.027 (.002)	.68 (.16)	15.53 (1.64)	.59 (.09)
5/22/85	.12 (.01)	.41 (.08)	.10 (.00)	1.65 (.09)	43.79 (5.52)	.021 (.003)	.62 (.03)	17.90 (0.58)	.39 (.02)
7/11/85	.15 (.00)	.19 (.11)	.06 (.00)	1.60 (.20)	12.10 (1.25)	.003 (.00)	.51 (.11)	19.94 (2.61)	.11 (.01)

Table 2b. Summary of metal concentrations (dry weight) in mussels (*Mytilus edulis*) deployed at Western Long Island Sound reference site (WLISrN).

Sampling Date	Mean Metal Concentration ± S.D. (μg/g dry wt of tissue)								
	Cd	Cr	Co	Cu	Fe	Hg	Ni	Zn	V
7/25/84	.75 (.11)	1.54 (.46)	.28 (.24)	8.70 (1.39)	178.44 (23.17)	.182 (.015)	2.95 (0.16)	151.40 (6.39)	1.43 (.22)
8/21/84	1.75 (.10)	1.00 (.30)	.70 (.26)	8.40 (0.35)	123.41 (10.37)	.168 (.020)	2.26 (0.39)	144.02 (5.54)	.44 (.10)
9/18/84	1.41 (.14)	21.11 (25.26)	1.30 (.51)	8.21 (1.60)	307.73 (171.53)	.178 (.029)	10.96 (9.13)	160.32 (34.68)	.86 (.05)
11/9/84	1.94 (.34)	3.47 (3.03)	.76 (.15)	8.90 (0.31)	322.87 (36.57)	.227 (.021)	4.36 (1.94)	227.30 (61.74)	1.92 (.47)
12/11/84	1.95 (.31)	2.85 (.85)	.73 (.10)	12.54 (2.15)	276.62 (41.52)	.228 (.022)	4.40 (1.04)	183.23 (12.22)	.82 (.03)
12/28/84	2.49 (.14)	5.81 (3.40)	.86 (.23)	15.32 (1.16)	329.53 (61.89)	.228 (.020)	6.33 (2.51)	202.24 (28.92)	1.52 (.13)
2/11/85	2.67 (.21)	2.44 (0.14)	3.51 (1.82)	17.94 (1.31)	520.29 (125.43)	.315 (.016)	3.66 (0.20)	180.99 (35.58)	2.34 (.69)
3/26/85	1.16 (.07)	1.55 (0.46)	.66 (.07)	13.28 (0.51)	257.24 (29.62)	.175 (.009)	2.38 (0.18)	136.66 (0)	2.34 (.13)
4/25/85	0.52 (.07)	4.59 (1.86)	0.33 (.03)	8.66 (0.59)	266.35 (28.12)	.150 (.00)	3.85 (1.09)	87.75 (3.18)	3.32 (.61)
5/22/85	0.68 (.07)	2.23 (0.46)	0.53 (.02)	8.99 (0.45)	239.04 (39.83)	.113 (.010)	3.37 (0.29)	97.30 (3.19)	2.14 (.18)
7/11/85	0.88 (.04)	1.13 (0.61)	0.33 (.02)	9.63 (0.88)	72.90 (6.29)	.019 (.001)	3.07 (0.60)	120.08 (13.68)	0.65 (.11)

Table 3a. Summary of metal concentrations (wet weight) in mussels (*Mytilus edulis*) deployed at Western Long Island Sound Center B mound (WLISc).

Sampling Date	Mean Metal Concentration ± S.D. (μg/g wet wt of tissue)								
	Cd	Cr	Co	Cu	Fe	Hg	Ni	Zn	V
7/25/84	.11 (.01)	.16 (.05)	.04 (.02)	1.25 (.03)	22.36 (2.78)	.024 (.003)	.30 (.03)	18.01 (3.39)	.13 (.01)
8/21/84	.17 (.05)	.28 (.06)	.05 (.04)	1.45 (.47)	18.41 (2.14)	.023 (.003)	.30 (.03)	20.66 (2.69)	.11 (.07)
9/18/84	.16 (.03)	.39 (.19)	.10 (.01)	1.03 (.27)	16.25 (4.41)	.026 (.006)	.33 (.07)	20.19 (4.96)	.08 (.02)
11/9/84	.17 (.01)	.60 (.15)	.06 (.01)	.93 (.10)	31.60 (2.34)	.022 (.001)	.60 (.19)	16.66 (5.14)	.13 (.03)
12/11/84	.18 (.01)	.54 (.13)	.09 (.00)	1.07 (.05)	42.25 (5.79)	.028 (.001)	.49 (.02)	15.43 (1.00)	.10 (.01)
12/28/84	.21 (.01)	.23 (.12)	.09 (.01)	1.43 (.10)	42.31 (2.63)	.023 (.003)	.38 (.07)	20.59 (1.83)	.18 (.04)
2/11/85	.21 (.01)	.63 (.30)	.28 (.04)	1.26 (.09)	47.20 (5.76)	.021 (.002)	.41 (.27)	14.06 (3.29)	.18 (.01)
3/26/85	.18 (.00)	.19 (.00)	.08 (.01)	1.46 (.06)	49.72 (7.13)	.027 (.001)	.21 (.06)	20.21 (2.50)	.29 (.03)
4/25/85	.12 (.01)	.48 (.09)	.05 (.01)	1.94 (.07)	42.94 (.86)	.023 (.004)	.52 (.03)	16.25 (1.66)	.41 (.04)
5/22/85	.13 (.01)	.35 (.10)	.08 (.01)	1.70 (.10)	37.73 (2.02)	.017 (.003)	.66 (.17)	16.52 (1.58)	.20 (.01)
6/26/85	.14 (.02)	.39 (.07)	.07 (.01)	1.60 (.31)	34.44 (4.75)	.022 (.004)	.62 (.22)	17.05 (5.25)	.27 (.07)

Table 3b. Summary of metal concentrations (dry weight) in mussels (*Mytilus edulis*) deployed at Western Long Island Sound Center B mound (WLISc).

	Mean Metal Concentration ± S.D. (μg/g dry wt of tissue)								
Sampling Date	Cd	Cr	Co	Cu	Fe	Hg	Ni	Zn	V
7/25/84	0.72 (.03)	1.10 (0.31)	.29 (.15)	8.70 (0.35)	155.44 (16.52)	.167 (.023)	2.11 (0.22)	127.42 (25.36)	0.89 (0.09)
8/21/84	1.13 (.27)	1.89 (0.44)	.37 (.18)	8.80 (2.18)	121.90 (8.95)	.153 (.015)	2.02 (0.09)	136.65 (11.52)	0.76 (0.42)
9/18/84	1.32 (.14)	3.20 (1.70)	.79 (.08)	8.19 (0.53)	129.72 (12.54)	.190 (.000)	2.61 (0.10)	162.08 (26.09)	0.61 (0)
11/9/84	1.84 (.22)	6.75 (2.18)	.70 (.11)	10.36 (1.11)	354.74 (53.90)	.243 (.025)	6.80 (2.47)	183.24 (42.41)	1.45 (0.38)
12/11/84	1.82 (.16)	5.49 (1.18)	.90 (.02)	11.00 (0.32)	433.26 (40.86)	.288 (.003)	5.06 (0.29)	158.56 (3.05)	1.06 (0.12)
12/28/85	2.12 (.19)	2.40 (1.36)	.87 (.10)	14.73 (1.82)	435.50 (49.91)	.240 (.039)	3.95 (0.92)	212.15 (29.75)	1.86 (0.47)
2/11/85	2.77 (.03)	8.33 (4.01)	3.62 (.64)	16.77 (0.67)	629.04 (74.47)	.285 (.022)	2.19 (2.57)	188.07 (47.00)	2.40 (0.28)
3/26/85	1.73 (.07)	1.82 (.07)	.79 (.04)	13.79 (0.44)	470.72 (91.64)	.257 (.003)	1.99 (0.63)	191.04 (31.59)	2.76 (0.23)
4/25/85	0.65 (.06)	2.68 (.46)	.29 (.04)	10.73 (0.22)	237.80 (8.60)	.130 (.022)	2.86 (0.18)	89.88 (8.00)	2.28 (0.18)
5/22/85	0.82 (.04)	2.19 (.62)	.49 (.05)	10.79 (0.59)	239.03 (11.38)	.107 (.021)	4.17 (1.06)	104.75 (11.22)	1.28 (0.04)
06/26/85	0.86 (.11)	2.44 (.02)	.47 (.02)	10.08 (0.38)	217.93 (13.43)	.137 (.008)	3.83 (0.75)	105.82 (12.91)	1.66 (0.16)

Table 4a. Summary of metal concentrations (wet weight) in mussels (*Mytilus edulis*) deployed at 500 meters west of B mound (500MW) in Western Long Island Sound.

Sampling Date	Mean Metal Concentration ± S.D. (µg/g wet wt of tissue)								
	Cd	Cr	Co	Cu	Fe	Hg	Ni	Zn	V
7/25/84	.10 (.01)	.12 (.04)	.03 (.02)	1.23 (.16)	18.65 (1.56)	.019 (.001)	.43 (.14)	14.96 (1.18)	.12 (.01)
8/21/84	.14 (.02)	.16 (.03)	.04 (.02)	1.12 (.09)	18.87 (3.33)	.023 (.003)	.24 (.04)	17.37 (3.33)	.09 (.03)
9/18/84	.15 (.02)	.40 (.02)	.08 (.01)	.97 (.15)	18.82 (.53)	.017 (.002)	.44 (.06)	14.48 (3.60)	.06 (.02)
11/9/84	.17 (.03)	.31 (.14)	.06 (.01)	.98 (.11)	30.20 (2.50)	.023 (.002)	.30 (.05)	15.16 (2.89)	.17 (.02)
12/11/84	.15 (.02)	1.11 (.44)	.05 (.01)	.85 (.13)	22.10 (2.68)	.014 (.003)	.59 (.19)	11.36 (3.60)	.07 (.01)
2/11/84	.25 (.02)	.16 (.02)	.29 (.01)	1.51 (.10)	44.39 (5.45)	.025 (.002)	.30 (.05)	16.63 (1.45)	.17 (.01)
3/26/85	.17 (.02)	.18 (.04)	.08 (.01)	1.67 (.15)	51.53 (9.20)	.026 (.004)	.22 (.02)	19.23 (3.06)	.30 (.04)
4/26/85	.11 (.01)	.38 (.06)	.05 (.00)	1.80 (.07)	45.24 (1.53)	.026 (.002)	.64 (.14)	15.43 (1.22)	.55 (.06)
5/22/85	.13 (.01)	.33 (.09)	.08 (.01)	1.87 (.16)	36.48 (2.54)	.017 (.001)	.61 (.21)	16.32 (1.15)	.22 (.02)
6/27/85	.16 (.01)	.38 (.01)	.07 (.01)	1.78 (.26)	39.21 (5.91)	.022 (.003)	.68 (.10)	21.26 (.05)	.36 (.02)

Table 4b. Summary of metal concentrations (dry weight) in mussels (*Mytilus edulis*) deployed at 500 meters west of the B mound (500MW) in Western Long Island Sound.

	Mean Metal Concentration ± S.D. (µg/g dry wt of tissue)								
Sampling Date	Cd	Cr	Co	Cu	Fe	Hg	Ni	Zn	V
7/25/84	0.73 (.008)	0.90 (.35)	0.25 (.15)	8.90 (.35)	137.05 (24.96)	.142 (.008)	3.05 (0.76)	108.97 (8.45)	0.88 (0.15)
8/21/84	0.99 (.15)	1.17 (.26)	0.26 (.15)	8.20 (.61)	138.56 (25.11)	.168 (.021)	1.79 (0.30)	127.42 (25.36)	0.63 (0.25)
9/18/84	1.33 (.14)	3.49 (.17)	0.69 (.09)	8.37 (.82)	164.02 (11.25)	.145 (.009)	3.83 (0.29)	125.06 (23.84)	0.56 (0.19)
11/9/84	1.78 (.17)	3.35 (1.65)	0.69 (.06)	10.36 (.55)	323.44 (52.62)	.225 (.017)	4.38 (2.34)	162.08 (15.87)	1.78 (0.09)
12/11/84	2.09 (.13)	13.86 (7.47)	0.76 (.20)	12.53 (1.75)	318.40 (65.83)	.200 (.025)	8.56 (3.51)	162.08 (49.98)	1.06 (0.24)
2/11/85	2.91 (.24)	1.88 (.37)	3.41 (.77)	17.65 (1.41)	517.86 (24.46)	.287 (.012)	3.53 (0.86)	196.57 (35.38)	2.02 (0.24)
3/26/85	1.49 (.14)	1.64 (.55)	0.74 (.04)	14.66 (.76)	457.05 (96.16)	.233 (.022)	1.95 (0.36)	169.65 (26.54)	2.64 (0.23)
04/26/85	0.63 (.06)	2.18 (.41)	0.29 (.04)	10.21 (.44)	256.42 (11.98)	.147 (.010)	3.66 (1.04)	87.76 (11.45)	3.11 (0.43)
05/22/85	0.74 (.04)	1.91 (.48)	0.45 (.05)	10.66 (.77)	207.99 (10.75)	.097 (.006)	3.49 (1.20)	93.05 (4.86)	1.25 (0.11)
06/27/85	0.99 (.02)	2.44 (.02)	0.45 (.04)	11.24 (1.40)	247.73 (31.83)	.140 (.018)	3.99 (0.55)	134.67 (3.72)	2.31 (0.10)

Table 5. Summary of PCB concentrations in mussels (*Mytilus edulis*) deployed at Ram Island reference site (RIr).

Sampling Date	Mean PCB Concentrations ± S.D.									
	Aroclor 1242		Aroclor 1254		Aroclor 1260		Aroclor 1254+1260		Total	
4/26/84	68* (7)	10** (0)	113 (15)	17 (3)	9 (2)	1 (0)	122 (17)	18 (3)	190 (17)	28 (3)
6/27/84***	54 (18)	8 (3)	79 (9)	12 (2)	8 (1)	1 (0)	87 (8)	13 (2)	141 (21)	21 (4)
7/26/84	103 (85)	16 (13)	142 (89)	22 (13)	8 (2)	1 (0)	150 (88)	23 (13)	253 (179)	39 (26)
8/22/84	40 (0)	5 (0)	65 (4)	8 (0)	9 (3)	1 (0)	74 (1)	9 (0)	114 (1)	15 (1)
9/19/84	27 (12)	3 (2)	40 (18)	5 (3)	5 (4)	1 (1)	45 (20)	6 (3)	72 (32)	9 (5)
11/2/84	75 (33)	7 (3)	33 (34)	3 (3)	24 (25)	2 (2)	58 (20)	5 (2)	133 (52)	12 (4)
12/13/84	52 (7)	6 (1)	0 (0)	0 (0)	122 (43)	15 (6)	122 (43)	15 (6)	174 (50)	22 (7)
1/3/85	63 (15)	7 (2)	12 (20)	1 (2)	46 (36)	5 (4)	58 (16)	6 (2)	121 (26)	12 (4)
2/13/85	62 (18)	10 (3)	38 (12)	6 (2)	5 (0)	1 (0)	43 (12)	7 (2)	105 (22)	17 (4)
3/28/85	85 (5)	15 (2)	47 (6)	9 (3)	10 (9)	2 (2)	57 (13)	10 (3)	142 (19)	25 (6)

Table 5, continued.

Sampling Date	Aroclor 1242		Aroclor 1254		Aroclor 1260		Aroclor 1254+1260		Total	
	Mean PCB Concentrations ± S.D.									
4/26/85	61 (24)	10 (5)	18 (31)	3 (5)	62 (49)	9 (7)	80 (20)	12 (2)	141 (6)	22 (2)
5/24/85	78 (12)	14 (3)	29 (4)	50 (6)	94 (15)	76 (13)	123 (19)	27 (6)	201 (31)	40 (9)

* expressed in ng/g dry wt ± S.D.
** expressed in ng/g wet wt ± S.D.
*** baseline

Table 6. Summary of PCB concentrations in mussels (*Mytilus edulis*) deployed at Western Long Island Sound reference site (WLISrN).

Sampling Date	Aroclor 1242		Aroclor 1254		Aroclor 1260		Aroclor 1254+1260		Total	
	Mean PCB Concentrations ± S.D.									
7/25/84	68* (14)	10** (2)	144 (21)	21 (3)	18 (4)	3 (1)	162 (25)	23 (3)	230 (19)	33 (3)
8/21/84	69 (39)	9 (5)	160 (60)	21 (7)	31 (25)	4 (3)	191 (61)	25 (7)	260 (97)	34 (12)
9/18/84	24 (8)	2 (0)	80 (12)	8 (2)	11 (8)	1 (1)	92 (17)	10 (2)	116 (23)	12 (2)
11/9/84	64 (27)	6 (2)	90 (27)	8 (2)	22 (4)	2 (0.24)	112 (30)	10 (2)	177 (55)	16 (4)
12/11/84	57 (6)	5 (1)	40 (69)	3 (6)	89 (42)	8 (5)	129 (39)	12 (3)	186 (44)	17 (4)
12/28/84	56 (9)	5 (1)	13 (23)	1 (2)	92 (82)	8 (8)	106 (62)	9 (6)	161 (71)	14 (7)
2/11/85	75 (22)	7 (2)	95 (36)	9 (3)	37 (38)	3 (3)	132 (68)	12 (6)	207 (98)	19 (8)
3/26/85	52 (15)	7 (2)	65 (23)	9 (3)	17 (10)	2 (2)	82 (33)	11 (5)	133 (44)	18 (6)
4/25/85	158 (136)	28 (23)	27 (46)	5 (8)	319 (379)	56 (64)	346 (349)	61 (59)	504 (484)	88 (82)

Table 6, continued.

Sampling Date	Aroclor 1242		Aroclor 1254		Aroclor 1260		Aroclor 1254+1260		Total	
	Mean PCB Concentrations ± S.D.									
5/22/85	113 (24)	21 (6)	124 (25)	23 (6)	31 (14)	6 (3)	156 (39)	29 (9)	269 (62)	50 (14)
7/11/85	111 (19)	17 (3)	196 (33)	27 (4)	27 (7)	6 (1)	222 (38)	33 (5)	333 (57)	48 (8)

* expressed in ng/g dry wt ± S.D.
** expressed in ng/g wet wt ± S.D.

Table 7. Summary of PCB concentrations in mussels (*Mytilus edulis*) deployed at Western Long Island Sound Center B mound (WLISc).

Sampling Date	Aroclor 1242		Aroclor 1254		Aroclor 1260		Aroclor 1254+1260		Total	
	Mean PCB Concentration ± S.D.									
7/25/84	51* (14)	7** (2)	133 (44)	19 (6)	16 (10)	2 (1)	149 (54)	21 (8)	200 (68)	29 (10)
8/21/84	55 (17)	8 (2)	140 (27)	21 (4)	20 (0)	3 (0)	160 (27)	24 (5)	215 (37)	32 (5)
9/18/84	38 (16)	5 (3)	98 (39)	13 (8)	13 (7)	2 (1)	111 (45)	15 (9)	149 (61)	20 (12)
11/9/84	60 (20)	6 (2)	20 (35)	2 (3)	65 (37)	6 (3)	85 (17)	8 (2)	145 (33)	13 (4)
12/11/84	56 (15)	5 (2)	44 (39)	4 (4)	73 (92)	7 (9)	118 (54)	12 (6)	174 (69)	17 (7)
12/28/84	44 (21)	4 (2)	0 (0)	0 (0)	131 (54)	13 (5)	131 (54)	13 (5)	175 (64)	17 (6)
2/11/85	68 (8)	5 (1)	38 (35)	3 (3)	42 (42)	3 (3)	80 (17)	6 (1)	148 (18)	11 (1)
3/26/85	108 (53)	11 (5)	115 (31)	12 (3)	30 (13)	3 (1)	145 (44)	15 (4)	253 (96)	27 (9)
4/25/85	138 (10)	25 (2)	78 (67)	14 (12)	96 (125)	17 (23)	173 (58)	31 (11)	311 (66)	56 (13)

Table 8. Summary of PCB concentrations in mussels (*Mytilus edulis*) deployed at 500 meters west of B mound (500MW) in Western Long Island Sound.

Sampling Date	Mean PCB Concentrations ± S.D.									
	Aroclor 1242		Aroclor 1254		Aroclor 1260		Aroclor 1254+1260		Total	
7/25/84	62* (81)	9** (2)	156 (30)	22 (5)	18 (4)	2 (1)	174 (34)	24 (6)	236 (41)	33 (8)
8/21/84	47 (7)	6 (1)	133 (20)	18 (3)	20 (0)	3 (0)	153 (20)	21 (3)	200 (27)	27 (4)
9/18/84	44 (10)	5 (1)	113 (46)	13 (6)	16 (8)	2 (1)	129 (54)	15 (7)	173 (64)	20 (8)
11/9/84	78 (49)	7 (4)	40 (69)	3 (6)	83 (52)	8 (5)	123 (28)	11 (1)	201 (74)	19 (5)
12/11/84	70 (36)	5 (3)	0 (0)	0 (0)	140 (10)	10 (1)	140 (10)	10 (1)	210 (44)	15 (4)
2/11/85	42 (18)	4 (1)	15 (26)	1 (2)	70 (51)	6 (4)	85 (28)	7 (2)	127 (26)	11 (1)
3/26/85	55 (22)	6 (3)	90 (18)	10 (3)	23 (3)	3 (1)	113 (20)	13 (4)	168 (42)	20 (7)
4/26/85	118 (8)	21 (2)	68 (59)	12 (11)	85 (113)	15 (20)	153 (55)	27 (10)	271 (47)	48 (9)
5/22/85	178 (10)	31 (2)	129 (111)	23 (20)	264 (196)	46 (34)	393 (183)	69 (31)	571 (188)	100 (31)
6/27/85	136 (21)	27 (5)	189 (30)	164 (23)	215 (34)	282 (45)	404 (64)	118 (29)	540 (140)	140 (23)

* expressed in ng/g dry wt ± S.D.
** expressed in ng/g wet wt ± S.D.

Table 9. Summary of PCB concentrations in mussels (*Mytilus edulis*) deployed at Latimers Reference Site (LATr).

Sampling Date	Mean PCB Concentrations ± S.D.									
	Aroclor 1242		Aroclor 1254		Aroclor 1260		Aroclor 1254+1260		Total	
3/26/85*	102** (17)	31*** (5)	18 (3)	31 (5)	89 (15)	72 (12)	107 (18)	42 (7)	209 (35)	73 (12)
4/11/85	151 (25)	104 (17)	51 (9)	88 (15)	280 (46)	287 (48)	331 (55)	221 (37)	482 (80)	324 (59)
5/24/85	78 (13)	8 (2)	0 (0)	0 (0)	135 (22)	17 (3)	135 (22)	17 (3)	213 (35)	24 (5)
6/27/85	122 (20)	69 (12)	151 (25)	83 (15)	18 (4)	10 (3)	169 (28)	91 (16)	292 (48)	160 (28)

* Baseline
** expressed in ng/g dry weight ± S.D.
*** expressed in ng/g wet weight ± S.D.